# The nature and scale of the Late Bronze Age economy in the Eastern Mediterranean for the period 1400-1175 B.C.

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# The Nature and Scale of the Late Bronze Age Economy in the Eastern Mediterranean for the Period 1400-1175 B.C.

**Volume 1 of 2 Volumes**

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Submitted to the University of Wales in fulfilment of the requirements for the Degree of Doctor of Philosophy.

Swansea University 2008

# Abstract

The question addressed by this thesis is the following: 'What was the scale of the Late Bronze Age economy of the Eastern Mediterranean for the period 1400-1175 B.C., and what does this say about whether the economy was formalist or substantive in nature?' After over a century of debate, the nature of the Late Bronze Age economy remains unresolved. This thesis attempts to add a new perspective to this debate by quantifying the scale of the manpower of the non-agrarian sector of the economy. These workers provided goods and services for state infrastructure projects, trade, and the conspicuous consumption needs of the élite. The approach taken provides answers as to whether the non-agrarian sector of the economy was in fact 'minimalist' in scale. The evidence has been accumulated from a wide range of textual, archaeological, ethnographic, archaeo-scientific, and experimental archaeology with the aim of reaching a conclusion as to whether the economy was embedded in the institutions of the state (substantive) or whether it was self-regulating in nature, by means of a market that responded to the forces of supply and demand (formalist). Two regions have been selected to represent the Eastern Mediterranean: Cyprus and Egypt, and these were chosen because they display a range of contrasting characteristics which represent two types of agrarian practice and two economies of different size.

The findings of this study show that the economies of both Cyprus and Egypt were not minimalist in scale, and that some attributes normally associated with formalism were in place by the end of the LBA. The overall operation of the economy, however, was still deeply embedded within the institutions of the state and therefore substantive in nature.

# Declaration

This work has not previously been accepted in substance for any degree and is not concurrently submitted in candidature for any degree.

Signed ...(candidate)

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# Statement

This thesis is the result of my own investigations except where otherwise stated. Other sources are acknowledged by footnotes giving explicit references. A bibliography is appended.

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# Acknowledgements

It would not have been possible to undertake and to complete this research without the encouragement of my friends and family. I am deeply grateful for the love, help and support of my wife Joan. Without her encouragement I would have faltered but together it has been a great adventure. My special thanks go to my two supervisors, Dr. David Gill and Dr. Kasia Szpakowska, whose enthusiasm for Ancient History inspired me to take my studies further. Finally my thanks to all the friends I have made at Swansea and the Sackler since I started my postgraduate research.

# Chapter 1: Thesis Introduction

## 1.1 Aims and objectives

The aim of this thesis is to provide a quantitative interpretation of the Late Bronze Age economy and to use this analysis to add a new dimension to the current debate on whether the Late Bronze Age economy during the period 1400-1175 B.C. was formalist or substantive in nature.[1] Substantivists maintain that in ancient societies the economy was embedded within the élite's socio-economic patterns of behaviour, while formalists believe that modern economic theory is universally applicable to both antiquity and the modern-day economy, as making rational choices an attribute that transcends time. Rational choice creates a market where the prices of exchanged products are governed by the forces of supply and demand.[2] This substantive/formalist debate has been ongoing for the last 120 years, and no definitive resolution has been reached. The approach here has been to quantify the manpower required to feed both the food-producing agrarian sector and the non-agrarian manpower of the economy. Without a harvest surplus over and above that required to feed the farmers and their families, the non-agrarian sector of the economy could not have been supported. Previous scholarship has concentrated on textual and archaeological evidence to draw parallels between substantive or formalist economic principles. This thesis provides an assessment of the manpower which was required to meet the basic needs of a LBA culture to feed, clothe, and provide shelter, and defines the scale of the economy that could support 'added-value' production of goods and services for trade and/or the conspicuous consumption needs of the élite. 'Added-value' is the term used for the increase in value of a product or service as a result of a particular activity. These activities

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[1] The Late Bronze Age will be referred to hereafter as the LBA. The terms 'Stone Age', 'Bronze Age' and 'Iron Age' are in many cases historical misnomers and date back to the work of Christian Jürgensen Thomsen [1788-1865]. While curator of the antiquities collection at Copenhagen, he classified artefacts into what has now become known as the 'Three Age System'. In many ways 'Copper Age' would be more applicable than the term 'Bronze Age' as arsenical bronze (natural occurring alloy of copper and arsenic and discussed in more detail below in Section 5.1) was commonly used to make artefacts in the LBA. Similarly copper and tin bronzes continued to be used for the production of artefacts throughout the Iron Age.

[2] Morley 2004: 43-45. Hereafter market refers to its modern economic abstract sense and not a physical marketplace. It is defined as the interaction between the supply and demand of products or services to determine the market price that dictates the quantity bought and sold. By convention modern economic theory is referred to as Neo-Classical economics and will be used hereafter.

within the context of this thesis could include any processing, assembling, handling, or transport of materials or finished products. For example, the production of a bronze chisel is an added-value process, as raw black copper has to be refined, alloyed with tin, and cast into ingots, moulds made and prepared, bronze ingots re-melted and poured into moulds, and finally the moulded tool must be annealed and work-hardened to make it usable as a chisel. The sum of the manpower costs throughout this process, including handling and transport, is referred to as the added–value component of the process. For this thesis this component is the sum of the man-days required to complete each part of the process.[3] This balance between food-producing and non-food-producing workers is therefore central to any discussion on the nature of the LBA economy.

Quantifying the scale of the non-agrarian sector identifies its boundaries and the degree of flexibility that the élite had to prioritise non-agrarian manpower. If the non-agrarian sector of the economy was negligible, then debate is meaningless and the economy would be substantive. If textual and archaeological records indicate that decision-making processes were embedded in the institutions of the state, then the economy was substantive. If however textual and archaeological evidence indicate that the prices of goods and services were wholly or partly independent of the élite and followed the forces of supply and demand, then the economy would be shown to be either an embryonic or a fully-developed formalist economy.

Two regions have been chosen for these quantitative studies: Cyprus and Egypt. Cyprus was chosen as representative of dry farming regions of the north-eastern Mediterranean, and because of the important part it played in the interregional copper trade.[4] Egypt has been chosen because it represents a region which was totally dependent on irrigation to grow food, produced regular food surpluses which, when

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[3] Typical examples of added-value manufactured goods in the LBA are Mycenaean and Cypriot decorated pottery, seals, jewellery, carved ivories, textiles, perfumed oils, furniture, stone and metal vessels, tools, and weaponry.

[4] By convention, dry farming is normally defined as those areas which have a rainfall between 380 mm and 500 mm per annum and some form of irrigation is available. Without irrigation rainfall limits for dry farming lie between 500-750 mm (Widtsoe 1913: 11-14). A working assumption is for satisfactory growth a weight ratio of 1:750 for dry matter produced to rainfall (Widtsoe 1913: 15-18). An important consideration if cereals are to be grown is that the bulk of this rainfall must fall in spring and early summer (Widtsoe 1913: 28-30). This will be discussed in more detail in Chapter 3.

combined with tribute from regions under the hegemony of Egypt, made it the largest economy in the LBA Eastern Mediterranean.

The specific objectives of this thesis are to investigate two main areas of the LBA economy for the period 1400-1175 B.C.: a quantification of the scale of the LBA economy and come to a position on the nature of the LBA economy.

The questions which are asked to quantify the scale of the LBA economy are:

1. What size of workforce in the agrarian sector was needed to feed the total population?

2. What size of harvest surplus was needed to support non-agrarian activities?

3. What was the proportion of the total manpower involved in non-agrarian activities required to satisfy the demand for cloth, domestic and state buildings, bronze production, and luxury items for trade or for the internal conspicuous consumption of the élite?

4. What was the impact of harvest failures on these manpower resources, and to what degree could this be mitigated by providing a food buffer in state granaries?

The questions which are asked in this thesis to assess the nature of the LBA economy are:

1. Was the LBA economy for the period under study 'minimalist' and 'primitive' in scale?

2. Did LBA administrators have cost accounting processes that could apportion cost and were these used to determine the value and price of goods traded?

3. Were the prices of goods traded between regions administered and controlled by the élite (substantive) or were they allowed to move as a result of changes in supply and demand (formalist)?

4. Was the commodities trade, particularly metals, controlled by independent merchants or not?

5. Did the LBA transport system have the flexibility to respond to the fluctuating demands from a market-driven driven economy?

6. Did the LBA administration have the flexibility within its institutions to react in a timely manner to variations in supply and demand through the mechanism of price?

# 1.2 Scope and structure of thesis

## 1.2.1 Scope

The thesis will study the time period between 1400 and 1175 B.C., and, where possible, contemporary archaeological and textual sources are used for analysis. However, as with any period in antiquity, gaps do exist, particularly in textual records. Texts and archaeological evidence from outside the period in question have been used if they are relevant and contribute to the understanding of the topic under review.

The Eastern Mediterranean is defined for the purposes of this study as within the boundaries of Egypt, the Northern and Southern Levant, Ugarit, Anatolia, and Cyprus (Figure 1.1). Rhodes is considered in this study to be a gateway or link on the boundary between the Eastern Mediterranean trading network and the Aegean trading network, and then onwards to the Central Mediterranean trading network.[5] Figure 1.2 summarises the political situation of the Eastern Mediterranean and Mesopotamia in the LBA, showing the strategic position of Ugarit between the Hittite and Egyptian spheres of influence, the diminishing power of the Mitanni, and the rising power of Assyria to the east.

An end date of 1175 B.C. has been chosen, as the collapse of the palace-dominated economies, due in part to the invasion of the Aegean and Eastern Mediterranean by the Sea Peoples (ca. 1210-1180 B.C.), provides a convenient end-point.

## 1.2.1 Structure

In order to understand the mechanisms responsible for the operation of LBA economy a number of approaches have been used. First, in chapters 3-6 the context, the appropriate evidence, and the processes which define LBA food production, cloth production, domestic and state building construction, and bronze production are presented. Each of these chapters analyses the end to end process and quantifies the manpower required to support them.

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[5] These trading networks, and the role of gateways and sea hubs and their inter-relationships, are discussed in Chapter 7, Section 7.3 from the viewpoint of Wallerstein's 'world system' model (Wallerstein 1974a).

Chapter 7 uses these outcomes to determine the scale and nature of the LBA in three ways:

1. The first part determines the scale of the non-agrarian workforce based on average harvest yields to determine whether the LBA economy for the period chosen and whether it was at a subsistence level or had the capacity for significant investment in state infra-structure, trade, and or conspicuous consumption.

2. The second part reflects the fact that harvest yields did vary significantly from year to year in antiquity. The analysis assesses the impact of this on the manpower available for non-agrarian activities.

3. Finally the evidence is examined as to how the élite organised and directed non-agrarian workforce, from this a position is taken on whether the economy was embedded in the economy or was directed to produce goods and services to satisfy a market driven economy.

This thesis contains a large amount of interrelated data, so a nomenclature system has been used to relate chapter numbers to spreadsheet data, figures, tables, and schematic drawings. Tables and schematics are included within the chapter text. For each of these, the chapter number is given first, followed by its sub-reference. For example, the first schematic in Chapter 2 displays the numbering system Schematic 2.1. The output from the spreadsheet calculations are summarised in reports: for example, the sixth report in BRONZECALC would be Report 6.6, i.e. the sixth chapter and the sixth report.

The thesis is published in two parts; the main text is in Volume 1. Appendices, glossaries, figures, a printout of the spreadsheets used to analyse the LBA economy, and the bibliography in Volume 2. The purpose of this is to enable the reader to refer to Volume 2 concurrently with the main text in Volumes 1.

# 1.3 Methodology

## 1.3.1 Systems modelling of ancient processes

Hopkins defined a model as a simplification of a complex reality, designed to show up the logical relationships between its constituent parts.[6] The *chaîne opératoire* methodology has been used extensively in this thesis to provide a framework for analysing ancient processes into a logical flow of deliberate sequences of work activities that define the resources required in temporal and spatial terms to operate the process. The technique was developed by the French and brought into prominence and applied to the study of prehistoric technologies by Leroi-Gourhan, Lemonnier, and Schlanger among others.[7] *Chaîne opératoire* methodology has been used to identify the LBA agricultural process, cloth production, domestic and public buildings based on mud brick construction, and bronze production. The time needed to complete each activity can be obtained either from experimental archaeology and or archaeo-ethnographic evidence as discussed below. The time taken to complete each part of the process can be measured to create a time-file, and therefore it is possible to calculate the manpower needed to complete the task. The time-files measured are a valuable source of evidence to be used in the models developed for this thesis.

The use of *chaîne opératoire* and other scientific, mathematical, and statistical techniques became popular in the 1960-1970s by those scholars that attempted to isolate and study the different processes at work within a society, and between societies, that has now became known as processual archaeology.[8] They viewed human behaviour as a point of overlap between numerous processes each of which encompassed both cultural and non-cultural phenomena.[9] Their strategy was to isolate and study these processes with the aim of reconstructing them as a mathematical model. To do this they used quantitative data analysis techniques to

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[6] Hopkins 2002: 191-192.
[7] Audouze 1999: 167-175, Edmonds 1990: 56-57, Leroi-Gourhan 1965: 35, Lemonnier 1976: 100-151; Lemonnier 1992, Schlanger 1990: 18-26.
[8] Renfrew and Bahn 1996: 448.
[9] Flannery 1967: 120.

provide insights into the past that they considered to be denied to those using more traditional approaches.[10]

This systems approach has been criticised by many scholars who support the post-processual school of archaeology.[11] Hodder believed processual archaeology was flawed because it ignored or under-emphasises the role of the individual:

> 'The approach is not able to account for the great richness, variability, and specificity of cultural production, and individuals and their shared thoughts are passive by-products of 'the system''.[12]

This thesis argues that a quantitative systems approach is a valuable input to our understanding of ancient processes and is not in conflict with post-processional *archaeology*. Rather this thesis provides a quantitative framework for the LBA economy within which post-processual interpretation can take place. It is within this framework of the manpower requirements to support the agrarian and non-agrarian sectors of the LBA economy the decision making criteria open to the élite can be postulated.

## 1.3.2 Sources of data used within the model

Experimental archaeology assists our understanding of past behaviour in two ways: replicating the processes that made up daily life in a controlled scientific manner and duplicating the tools and products made from them.[13] Experimental archaeology and systems process modelling are symbiotic. As stated above one of the most useful aspects of modelling processes is that by its nature the model identifies gaps in our knowledge that may not have been previously obvious. This can optimise the return on investment of future experimental archaeology research projects by organising them to focus on those areas in such a manner they fill those gaps. Experimental archaeology can be costly in time, materials, and expertise that set out to measure

[10] Shennan 1997: 2-3.
[11] The term system in this context is the structural framework within which a number of processes are employed. For example the LBA economy is a system and bronze production is a process within it.
[12] Hodder 1991: 34. For an example of Hodder's approach and challenging interpretation of the past see his paper on 'The Decoration of Containers: An Ethnographic and Historical Study' (Hodder: 71-94).
[13] Coles 1973: 14-18 and Reynolds 1999: 156-162.

maximum and minimum throughput of ancient processes.[14] Computer models developed to reflect the findings of experimental archaeology studies can be used to extrapolate other variables not covered in the studies because of possible prohibitive resource implications of repeating the experiments.

A limited number of experiments were carried out by the author where gaps existed in other sources: these comprised the broadcasting of seed (Chapter 3), the preparation of flax (Chapter 4), and the beneficiation of ores (Chapter 6).

Ethno-archaeology also complements *chaîne opèratoire* and experimental archaeology described above. This approach came to prominence in the processual period of archaeology during the 1960s and 1970s, with Lewis Binford's study of hunter-gatherers.[15] Ethno-archaeology uses the evidence of contemporary cultures to understand the behavioural relationships which underpin the production of their material culture.

Combining all three methods with evidence from textual and archaeological records helps to highlight the technological and process problems faced by ancient cultures which are not immediately apparent from the examination of archaeological records. These techniques will not in themselves prove how the ancients worked, but they will show us how they could have accomplished their work using the tools available to them.

## 1.3.3 Chronology

Chronology is particularly controversial in the Eastern Mediterranean regions in the LBA, with strong feelings expressed regarding the validity of 'high' (sometimes referred to as early or long) and 'low' (sometimes referred to as late or short) chronologies.[16] There is general consensus that the Egyptian chronology is the

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[14] See the experimental archaeology work of Merkel Craddock and Hughes 1985, Merkel 1983a: 173-178; Merkel 1983b, Tylecote, R.F. and J.F. Merkel. 1985, and Timberlake 1994: 121-130 in a later chapter on bronze production.

[15] Binford 1981, with associated bibliography.

[16] Weiner 2003: 363-402. Low chronology is based on the traditional approach of pottery typology relative to absolute dates in the Egyptian chronology (covered below), whereas high chronology is based on the scientific evidence of radiocarbon dating, dendrology and ice-core samples. Tests on ice-core samples from Greenland indicate a date range 1650-1643 B.C. for the eruption of Thera (Hammer *et al* 1987: 517-519). The low chronology gives a date range for the eruption of between 1560-1520 B.C. (Weiner 2003: 394 and Warren and Hankey 1989: 141-142, 215).

nearest to an absolute standard.[17] All other related regional chronologies based on pottery typologies attempt to link in to the Egyptian chronology when considering interregional contact and trade.[18] It is beyond the scope of this thesis to try and add any value to the high-low chronology debate, so a system has therefore been chosen that enjoys the greatest consensus, namely one based on 'low' chronology (Figure 1.3).[19]

## 1.3.4 Spreadsheet models

Five Excel spreadsheet models have been developed which replicate these ancient processes.[20] Each spreadsheet has a name, which is used in the thesis for reference. AGCALC calculates the food required to feed the population of Egypt and Cyprus assuming an average harvest yield as well as the manpower required to grow the food. FAMINE and GLUT reflects the variability of rainfall on the output from Cypriot agriculture, and, for Egypt, the impact of variations in the height of the Nile. CLOTHCALC determines the manpower to produce linen and woollen cloth. SHELTER analyses the manpower required to make the mud bricks used in Egypt for selected domestic and state infrastructure buildings. BRONZECALC calculates the manpower required to mine copper and tin, and then smelt them and alloy them to make bronze, and also estimates the demand for bronze in the LBA for the Egyptian Army, the agrarian sector, and the supply of tools for craftsmen. Each model includes databases of the data relevant to the process, and printouts of the spreadsheets and associated data bases are provided in Appendixes 4-8.

All calculations in the spreadsheets use SI (System International) units: kg for weight, m for length, $m^3$ for volume, and $kg/m^3$ for density. The manpower required

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[17] The Egyptian chronology has fixed dating points, derived from texts that link the start of the Egyptian Civil Year and Pharaonic regnal years to the first heliacal rising of Sirius on the Eastern horizon. The first rising of the Sirius star is called heliacal because it rises in the East, just before the sun with an elapse time between two heliacal cycles of 365¼ days. Each successive day Sirius rises slightly earlier before hidden by the sun until a point is reached where it becomes invisible at dawn because the star has already set on the horizontal horizon. These texts are known as the corpus of Sothic dates, and from them absolute dates can be derived to an accuracy of 1-4 years within the Great 1460 year cycle of the Sirius star (Firneis 2000: 58-59 and Goddio-von Bomhard 2005: 65-70, Figure 2).

[18] It is important to relate pot fabrics as well as style when linking pottery typology to chronology. A good example of this approach is Hatcher 2007 linking style and fabric of Cypriot White Slip I and II pottery to specific clay beds in the Apliki and Sanidha regions of the Troodos Mountains.

[19] Bell 2005: 12, Figure 1.

[20] Excel © is a registered product of The Microsoft Corporation.

for each process is defined either in the number of days, or years if more appropriate, required to complete an activity that was part of the process (man-days or man-years). If assumptions have been taken from pre-modern sources, they are for the sake of clarity given in terms of the units presented, and followed by their SI equivalents in brackets.

## Management of data

It is in the nature of any attempt to replicate ancient processes in a systemised way that assumptions have to be made where our knowledge is limited. Where gaps exist in the archaeological or textual records this thesis has, where possible, based assumptions on published experimental archaeology and ethno-archaeological papers as well as extensive use of the evidence of ancient processes shown sometimes in great detail in Ancient Egyptian tomb paintings. The benefit of systems modelling, particularly if computer based, is the ease in which data parameters can be changed to assess the reasonableness of some of the more speculative assumptions. Replicating ancient processes using computational techniques is therefore not a linear process but is better viewed as a continuous loop, facilitating refinement of assumptions that may be impossible using more traditional fields of study. As a part of this process extensive testing of the Excel models were carried out to determine the potential range of error on the main outcomes of the model. When using ethnographic and historic data such as harvest yields, the distribution is tested to see if it follows a normal distribution using the Chi Square test.[21] If so, confidence limits at the 95% level of significance are used. If not, two additional choices are available the median or the average of the distribution is available if applicable.[22] It is the scale and the proportions of the different elements of cost incurred in antiquity that is important for this study, not the exact absolute nature of the result. In many ways it is the questions that arise out of the process analysis that are as valuable as the end results provided by the model.

[21] For example Reports 2.34a-b.

[22] To ensure maximum flexibility in testing the model or when the model is applied to other time periods or regions, with possible different yield distributions, a field is provided in the spreadsheet (highlighted red) for entry for the following three cases: 1 for median, 2 for average, and 3 for 95% confidence limits (for example reports 3.15c and 3.16a).

# Chapter 2: The LBA economy in context

This section will provide context to the thesis by providing a review past and present of the substantive/formalist debate, the relevance of 'cost' to our understanding of the operation of the LBA economy, and why the level of interregional contact and the scale of trade are indicators of the nature of the LBA economy.

## 2.1 The substantive/formalist debate

Whether the LBA economy was formalist or substantive in nature is an ongoing debate among economic scholars which has remained unresolved for over a century. There have been many valuable studies which have addressed the nature and workings of the ancient economy, and most have concluded that it was 'primitivist', 'minimalist', and substantive in nature, based on internal redistribution (principally of agrarian products) controlled by the élite, with gift exchange as the prime mechanism for the movement of goods between ruling élites.[23] Those who subscribe to a primitive or minimalist view see the economy as almost totally agrarian, with non-agrarian technology at a primitive and minimal level. Because of the overlap in meaning between primitivism and minimalism, the term 'minimalism' will hereafter be used to describe both, unless a particular scholar who specifically used one or the other is being cited.

One of the first scholars to attempt to articulate the nature of the ancient economy was Karl Bücher in the 1890s. Bücher took a minimalist view of the ancient economy, linking it in terms of its centre of gravity, scale and organisation to production units that equated to the *oíkos* (family household).[24] In an *oíkos* economy, the various households or production units were responsible for the production of

[23] The terms 'primitivist', 'minimalist', and 'substantive' have a considerable overlap in the relevant literature, and they differ more in emphasis than in substance (Cooney 2007b: 80). Leading protagonists are Dalton 1961: 1-25 and Weber 1976 for primitivism, Finley 1973 and Weber 1976 for minimalism (note the overlap), and Polanyi 1957a: 243-270, Finley 1973 (again the overlap) and Janssen 1975b. For an Egyptian focus see Janssen 1975b: 131, 183-184 in particular, who equates the Ancient Egyptian economy to a peasant economy based on redistribution with minimal market activity. Janssen argues that the Egyptians regarded the economy lacked individualism a trait of market economies (Janssen 1975b: 137-139). Another substantive view of the Egyptian economy is that of Bleiberg 1988/9: 157-168 and Bleiberg 1995: 1375, who argue that the tomb scenes represent a physical marketplace where goods were bartered, and were not part of an abstract market that followed the laws of supply and demand.

[24] Weber 1976: citing Bücher 1893. Finley also took a similar view, as discussed below.

goods for their own use, storage of raw materials and goods, and the manufacture of indispensable goods for exchange.[25]

The first 'modernists' to challenge this minimalist view, were Meyer and Rostovtzeff. Meyer's work was based on a study of Mesopotamian texts, and concluded that only a quantitative and not a qualitative difference separated the ancient and modern economies.[26] Meyer believed that trade and added-value production was at a lower level in ancient economies than in the Neo-Classical economies, but that its nature was the same, with similar underlying structures and processes.[27] Rostovtzeff suggested that the Greco-Roman world was strongly influenced by the market-orientated economies of Mesopotamia and the Near East, moving from an *oíkos* economy to one which, though smaller in volumetric terms, possessed within it all the attributes of the modern economy.[28]

As a reaction to this 'modernist' view, Max Weber took a position that is both 'primitivist' and 'minimalist', arguing that the economies of antiquity were totally different in terms of scale and nature from those in the Middle Ages. He argued that the nature of the ancient economy was qualitatively different as well as in terms of scale. He concluded that the main inhibitors to the development of a market economy in antiquity were the limits on market production imposed by an inefficient and uneconomic transport system, the inherently unstable structure and formation of capital, the limitations of technology as regards the full exploitation of the potential labour force in large enterprises, and finally the limited degree to which cost accounting was possible, due to the inherent difficulty of apportioning the costs of slave labour.[29]

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[25] Pollock 1999: 118.

[26] Rostovtzeff's most famous works are The Social and Economic History of the Roman Empire (Rostovtzeff 1926) and The Social and Economic History of the Hellenistic World (Rostovtzeff 1941a).

[27] Meyer 1924: 77 ff. For a modern commentary of Meyer's and Rostovtzeff's work see Morley 2004: 37-38.

[28] Rostovtzeff 1941: 1301-1304, particularly 1303, where he goes further, concluding "The innovations in the organisation of economic life, all of which tended towards what, with all reserve, we may call 'capitalism'...".

[29] Weber 1976: 65-66. When Weber wrote about 'labour', he was referring to slave labour. For the purposes of this thesis, the difference between a slave and a normal manual worker is not relevant, as both have to be fed a minimum subsistence diet if they are to work effectively.

The debate between primitivists and minimalists on one hand and modernists on the other reached a new level of scholarly interest in the aftermath of the work of Karl Polanyi and Moses Finley in the 1950s. Polanyi and Finley promoted the argument that only substantivism provided an analytical framework which could explain the workings of the ancient economy.[30] Polanyi built on Weber's 'primitivist' view, concluding that the ancient economy was 'embedded' in society, rather than being a distinct economic activity. Polanyi proposed that it was this 'embedded' state that gave ancient cultures their unity, stability, and structure, and that within this institutionalised system, they had no concept or requirement for modern economics (hereafter Neo-Classical economics).[31] Finley argued that there were no wide-ranging markets in antiquity, and therefore the market could not organise and direct production, distribution, and consumption.[32] Oppenheim and Renger considered that, though there was a retail trade in metal commodities, because the demand for metals could not entirely be satisfied through gift exchange, there is no evidence that they were part of an integrated market transaction.[33] Polanyi shared the view that Neo-Classical economics were inappropriate to the study of the ancient economy, because the market economy tends to self-regulate and become separated from the rest of society.[34]

Polanyi proposed that the rules of reciprocity and redistribution, and through them communal obligations, underpinned the running of the economy.[35] The substantivists do not deny that exchange took place, particularly large-scale movements of commodities such as copper and tin, but suggest that the exchange rate was agreed between the supplying and receiving élites. Part of this process included gift exchange between ruling élites, which would have created an obligation on the part of the receiver to return the favour at some point in the future in a form required by

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[30] Polanyi 1957a, Polanyi 1957b, Polanyi and Dalton 1971, Polanyi and Pearson 1977, Finley 1973, and Finley 1985.
[31] Polanyi 1957a: 248.
[32] Finley 1973.
[33] Oppenheim 1957: 27-37 and Renger 1984: 31-123.
[34] Polanyi 1944: 135.
[35] Polanyi 1957a: 243-270, Polanyi 1957b: 12-26, Polanyi, Arensberg and Pearson 1957: 239-242, and Polanyi and Dalton 1971. The substantivists propose that redistribution was the mechanism used by the state to cascade down staples (mainly grain) from centralised storage to the non-agrarian workers.

the giver.[36] Firth proposes the main emphasis of the fulfilment of obligation lies in the desire to continue useful economic relations and the maintenance of prestige and power.[37] Polanyi and Finley propose that the whole process was strengthened through kinship within and across cultures, which often involved arranged royal marriages and was sometimes bound by treaty; ruling élite peers exchanged luxury goods through the mechanism of reciprocity to create and maintain social relations between, within and across cultures.[38] In a substantive economy, Polanyi postulated that the exchange of commodities and perhaps staples would have been administered and controlled between regions through 'ports of trade', where the goods were physically exchanged using exchange rates agreed between the ruling élites through formal treaties.[39]

The Ugarit texts provide a wide-ranging socioeconomic view of LBA society for the period under study. Two outstanding scholars, Heltzer and Liverani, conclude that Ugarit society operated at two levels: a palace-controlled sector with an associated hierarchy of royal dependents, and a semi-independent sector free to pursue private business activities, which was located in villages and estates in the Ugarit hinterland.[40] As part of this semi-autonomy, these villages paid agricultural produce and military service to the palace.

A different approach to that of Heltzer and Liverani is the recent work of Schloen, who presents a substantive patrimonial model of the ancient economy based on the

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[36] One of the best collections of texts demonstrating the gift exchange process are the cuneiform tablets known collectively as the Amarna letters. An excellent commentary on the Amarna letters with full translations can be found in Moran 1992.
[37] Sahlins 1972: 155 citing Firth 1959: 421.
[38] Humphreys 1969: 189, 194, 199 and Möller 2000: 16. The Amarna letters provide a wonderful insight into the obligations formed by these practices.
[39] Polanyi 1963: 30-45. Ports of trade were normally located on a riverbank or sea shore, but could also be found far inland, on the border of two ecological regions, such as highland and plain, but particularly on the edge of the desert (Polanyi 1963: 30-31). Ports of trade were involved with external exchange between regional élites, not internal trade within the region. He states. "Where present, it [single port of trade] was relegated to the background, or was merely lurking on the periphery" (Polanyi 1963: 30). The benefits to the foreign trader were that they were given civil protection, safe anchorage, quays, and storage (Polanyi 1957a: 263). The port of trade could be used by the host power to maintain control over external influences that could be disruptive to society in general (Humphreys 1969: 192).
[40] Heltzer 1976, Heltzer 1977: 203-211, Heltzer 1978, Heltzer 1979: 459-496, Heltzer 1982: 161-183, Heltzer 1987: 237-250, Heltzer 1996: 177-182, Liverani 1984: 33-44, and Liverani 1989: 127-168. This model is commonly referred to as a "two-sector approach" and will be used hereafter. A unity model favours a single palace-centred culture (Fleming 2002: 74). For a review of the Mesopotamian evidence for public and/or private enterprise see Lamberg-Karlovsky 1996.

patriarchal household.[41] Although his initial studies centred on the Ugarit texts, Schloen has applied his model to the kingdoms of the Near East and New Kingdom Egypt.[42] The characteristics of the patrimonial model are kinship, the inheritance of wealth, passed down the male line, a primarily agrarian culture, and a social structure of large extended families rather than nuclear families.[43] Schloen takes a unitary view of the ancient economy, while still allowing families to exhibit individuality; he considers that there was no difference between the socioeconomic structures of town and country.[44] The pyramidal nature of these extended family households is unified by the king as the symbolic head who gave stability and structure to society.[45] Schloen strongly defends the position that formalism does not have a monopoly on rational thought and action, proposing that this was simply different from Neo-Classical rationality.[46]

A minority of scholars believe that the ancient economy was to a greater or lesser extent a formalist economy in nature.[47] They subscribe to Meyer's view that the nature of the ancient economy differs fundamentally only in a quantitative and not a qualitative sense.[48] They suggest that the operation of the ancient economy was rational and that elements of modern economic theory can be applied to it. Sahlins suggests that much of the formalist/substantive debate arises from whether the scholars come from an anthropological or sociological tradition. Formalism from an anthropological position defines economy action as a category of behaviour as

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[41] Schloen 2001.
[42] Schloen 2001: 255-316.
[43] Schloen 2001: 101-111.
[44] Schloen 2001: 50-53.
[45] Schloen 2001: 65, 208, 230-231. This association between the pyramidal configuration of "nested" of households and the king was also noted by Fleming 2002: 76.
[46] Schloen 2001: 79-83 particularly 79.
[47] Scholars taking a formalist or lean towards the formalist position: Cook 1966: 323-343, Firth 1967: 1-27, Fogel 1964, Helck 1993: 39-40, Meyer 1924, Powell 1977: 23-39, Powell 1996: 244-242, North 1977: 703-716, North 1990, Schneider 1974, Silver 1983: 795-829, Silver 1985b, and Silver 2004: 65-87. Egyptologists who accept that some economic market forces were in place by the end of the New Kingdom are Cooney 2007a; 2007b, and 2007c, Earle 1977: 213-219, Eyre 1987b: 199-203; Eyre 1999: 53-54, Wilke 2000: 81-95, and Warburton 2007: 175-194. For a critique of the Polanyi approach to the Mesopotamian economy see Gleghill and Larsen 1982: 197-229. In 1993 the formalist position received a boost with the Nobel memorial prize presented to Robert W. Fogel and Douglas C. North for their work, which has become known as the 'New Economic History'. In particular they used extensive statistical analysis based on Neo-Classical economic theory to analyse the operation and nature of pre-modern economies.
[48] Meyer 1924: 79-168.

distinct from the substantive position as a category of culture.[49] He goes further saying the economy is the logic of effective action towards a goal: it is getting the most from the least of whatever it may concern.[50] The proposition of the formalists is that man has unlimited 'wants' that require a degree of rational economising because of the limited means available to satisfy them.[51] In terms of behaviour, formalists believe an important facet of human nature is the maximisation of scarce assets and the minimisation of risk.[52] Key to the formalist argument is the existence of a 'market' that balances supply and demand for goods through pricing mechanisms that regulate the flow of goods from one interested party to another. If demand is high, prices will rise, thereby lowering the demand for the goods, as they become unaffordable to some of the potential buyers. Von Mises' definition of a market captures its rational nature:

> The market is not a place, a thing or a collective entity. The market is a process, actuated by the interplay of the actions of the various individuals cooperating under the division of labour. The forces determining the continually changing state of the market are the value judgements of these individuals and their actions as directed by these value judgements.[53]

Responding to the formalists, Polanyi and Finley disagreed that modern economic theory applied to the ancient economies.[54] In particular they rejected the supposition that ancient cultures had the cost account processes which would be necessary for the management of a formalist market economy.[55] They also rejected the possibility that trade was stimulated by merchants seeking profitable exchanges. Finley totally rejected the formalist concept of a 'market', arguing that no one has convincingly shown that there existed in antiquity a single economic unit which interlocked

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[49] Sahlins 1969: 15.
[50] Sahlins 1969: 22.
[51] Schneider 1974 viewed human behavior as optimizing behavior, in the tradition of neoclassical economics. This optimizing behavior manifests itself cross-culturally, whether or not the populace had money or markets.
[52] Hafford 2001: 12-13.
[53] Von Mises 1949: 257-259.
[54] Polanyi and Finley believed that pre-modern and modern economies were so fundamentally different that they rendered the vocabulary of Neo-Classical economics inaccurate and misleading when applied to the study of ancient and tribal societies (Dalton and Köcke 1983: 26).
[55] Finley believed that the goals and social mores of ancient societies meant that ancient peoples saw no requirement to develop and apply economic accounting practices in the form we know today. Finley states that to judge ancient texts from the perspective of modern accounting practices shows a "fundamental misconception of what these writings were about" (Finley 1973: 21).

behaviour over a wide area.[56] Finley even went so far as to question whether the ancients had any concept of a Neo-classical economy:

> ... in fact [the ancients] lacked the concept of an "economy", and, a fortiori, that they lacked the conceptual elements which together constitute what we call the "economy".[57]

Supporting Finley's view, Janssen's research into the nature of the Egyptian economy states:

> ... odd as it may seem to be, profound knowledge of the modern market-directed economy proves to be of little value to the Egyptologist and may be obnoxious since it tends to blind him to the fundamental difference between the modern western world and Ancient Egypt.[58]

One practical argument against the operation of a market is that transport was slow and information critical to the operation of modern markets would have been lacking, rendering markets incapable of responding in time to reflect changes in supply and demand. As Morley points out, slow response is in marked contrast to modern markets, where exchange and price can be seen as a form of communication. In modern markets, merchants and traders respond instantly to the information they receive about the rates at which goods can be purchased and sold, adjusting their prices or exchange rates accordingly.[59]

Another area of disagreement between substantive and formalist positions is whether the ancient economy was minimalist in nature, as proposed by Karl Bücher. He and Weber argued that the demand for luxury goods of any sort was low, owing to the unequal distribution of wealth and the limited absolute size of the élite[60]. Finley takes the same view; using the lack of archaeological and literary evidence for trade in the ancient economy, he concludes:

> ... a silence that is explained in the simplest way, because there was effectively nothing to speak about.[61]

Substantivists accept that commodities were traded, particularly metals, but assert that this was through the vehicle of gift exchange or administered trade that passed

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[56] Finley asserts that "... a 'World Market' must embrace something considerably more that the exchange of goods over a large area" (Finley 1973: 34).
[57] Finley 1973: 21-22.
[58] Janssen 1975b: 131.
[59] Morley 2007: 26, 33.
[60] Weber 1976: 208.
[61] Finley 1973: 132-139, particularly page 136. Snodgrass 1991: 15-20 also takes the same position.

through ports of trade that were invested through the authority of formal treaties, as discussed above.[62]

In summary, the debate revolves around two conflicting concepts. The formalists believe that the ancient economy was managed by prioritising unlimited demands through the making of rational choices based on Neo-Classical economics. The substantivists, on the other hand, believe that ancient economies did not respond to unlimited demands by making rational economic choices, but instead the ruling élites made choices by prioritising demand. Substantivism involves a different form of rationality based on relationships, obligation, and social hierarchy.

[62] Snodgrass 1991: 16 summarises the views of many substantivists, who take the view that redistribution economies linked to ports of trade were primarily interested in procurement for their needs. He did not see trade as a commercial venture, the purpose of which was to make profit.

## 2.2 The significance of cost in the LBA economy

This thesis postulates that the 'cost' of production was as relevant an economic concept in the LBA as in post-coinage periods.[63] Manpower has been used as a base unit of measurement for determining the relative cost of the different activities that made up the LBA economy, including food production itself. Accumulating these base units for all activities that form part of the process provides the total cost of production.[64] This thesis proposes that at the macro level, if products and services were not exchanged at a minimum equal to the cost of production, economic recession and instability would follow.[65] There could have been many factors that triggered the collapse of the LBA economy ca. 1175 B.C.: famines due to natural causes, earthquakes, war, state mismanagement, or combinations of all four to different degrees. The net result, however, was the same: economic decline.

Comparing these production costs for different products and services with exchange values known from textual sources provides evidence as to whether goods were exchanged for profit, either by the state or by individuals. It is this process that goes to the heart of the formalist-substantive debate. Labour, including slaves, was not free, as workers had to be fed.[66] In a state controlled by a centralised bureaucracy, non-agrarian workers had to be fed from the surplus that the agrarian workers could provide and the palace or temple élite would have to prioritise as to how to allocate this surplus. Two main choices were open to them, namely to subsidise funerary

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[63] For the purposes of this thesis coinage is defined as having four attributes: a means of exchange, a mode of payment, a standard of value, and a way of storing wealth (Snell 1995: 1487). The first coins that fulfilled all four attributes were those introduced by the Lydians in ca. 650 B.C. The weights of the Lydian coins were standardised and made of locally available electrum, a natural alloy of gold and silver. The coins were stamped with symbols of the state which increased their prestige value (Snell 1995: 1494-1495). In the period under study proto-currencies existed but there is no consensus that all four attributes were fulfilled at the same time. The two extremes are well represented by Powell 2000: 5-23 who argues that money that is sufficiently like money to permit legitimate use of the term was already in place in Babylonia by the mid-third millennium. Diametrically opposed to this view is Renger 1995: 271-324 who argues that the ancient economy was based on redistribution and subsistence and that the textual evidence clearly shows that money played no part in the operation of the economy. This topic will be returned to in Chapter 6.

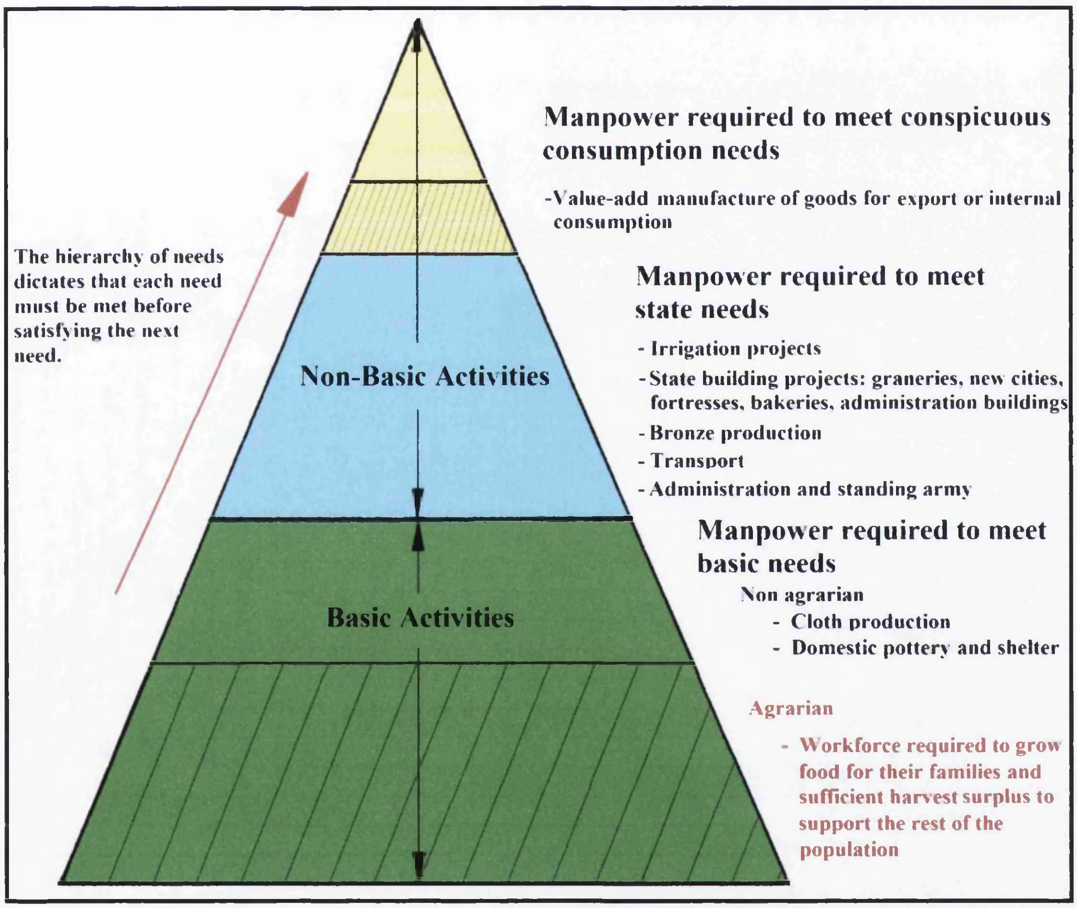
[64] Chapter 2 describes the agrarian model developed for this thesis. In this model the food required for any individual takes into account age, sex and the energy levels which needed to be satisfied, depending on the nature of work performed.

[65] Post processual interpretation may consider this as a case of imposing post industrial revolution values on the Ancient Economy. This thesis argues that recovering costs is an economic imperative applicable to any period.

[66] See Heltzer 1987: 237-250 for Ugarit, Eyre 1987b: 167-221 for Egypt and Giorgadze 1987: 251-256 for Hittite society.

activities and conspicuous consumption in daily life, or to subsidise state infrastructure projects such as the building and maintenance of irrigation canals and ports, or the exploitation of natural and mineral resources.

To investigate the consequences of this prioritisation of manpower, this thesis adapts the concept of the hierarchy of needs developed by Maslow.[67] Here it is a hierarchy of 'manpower needs' which is used, rather than Maslow's 'behavioural needs', as we can see in Schematic 1.1. below. A hierarchy of manpower was required to satisfy first the basic needs, that is, production of food, clothing, and shelter, followed by state infrastructure needs. Once these have been met, the final need to be satisfied was the conspicuous consumption requirements of the élite.




**Schematic 2.1: Hierarchy of manpower needs required to support the LBA economy**

[67] The concept of a hierarchy of needs was first used by the behavioural philologist Abraham Maslow who hypothesized that human endeavour could be explained in terms of striving to fulfil a hierarchy of needs that individuals attempt to meet; the accomplishment of one need allows release for the individual to fulfil another at a higher level (Maslow 1970). Maslow was a behavioural anthropologist who became the leader of the humanistic school of psychology in the US in the 1950s and 1960s. He developed the concept of the hierarchy of needs, the most basic being physical needs, followed by the other needs of security, belonging, esteem, and finally self-actualization. Each lower need has to be satisfied before the next one can be addressed.

The priorities chosen for the allocation of the surplus resided with the ruling élite, and, to ensure that the state operated effectively, state manpower needs would take a higher priority than allocation of manpower to meet the demands of conspicuous consumption. The surplus that remained for conspicuous consumption could either be exchanged by the élite for luxury goods, and/or used to feed their own craftsmen. These workers could produce prized goods which the élite would keep to fulfil their own conspicuous consumption needs, or else they could be exchanged with other ruling élites. The economic growth sustained throughout the period 1400-1175 B.C. was probably due to the ruling élites following these investment disciplines.

Modelling and quantifying the size of the agrarian sector not only provides a measure of the scale of the harvest surplus but also an objective indicator of the resources available to the élite, principally in terms of the manpower required for a workforce engaged in non-agrarian activities. It is the size of this workforce available for non-agrarian added-value activities that provides the stimulus and potential for interregional trade.

## 2.3 The significance of the scale of trade in the LBA economy

Copper and tin were the largest contributors to trade when taking into account their exchange values and the sheer quantity of both metals thought to be traded across the Eastern Mediterranean.[68] Reliable trading networks were imperative to the operation of Bronze Age societies, as copper is found in only a few regions in the Central and Eastern Mediterranean, and tin was probably imported from outside the region by the time of the LBA.[69] Common to all regions was the universal and growing demand for both tin and copper to make bronze, which was used throughout the period under consideration.[70] Those regions without indigenous metal resources had to develop other products and services to exchange for the copper and tin, and these products have been defined here as 'added-value' products. As bronze can be easily recycled, archaeological records understate demand, and calculations have been made to compensate for this factor in the estimate of bronze demand in Section 7.2.2.[71]

Archaeological and textual records indicate that long-distance trade was conducted in the Eastern Mediterranean at a hitherto unprecedented level during the period covered by this thesis. This was made possible by the development of long-distance sea transport, as demonstrated by the Ulu Burun, Gelidonya and Port Iria wrecks.[72] Despite the physical risks encountered on the part of the mariners and the financial risk taken by the ships' owners, the improvements in design, particularly of the keel and sails, reduced the risks of this low-cost method of transport.[73] Tin was probably imported from Central Asia, so other commodities, manufactured products, and

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[68] The total value is the product of quantities traded times their exchange value per unit weight. For estimates of the demand for copper and tin in the LBA see Section 7.2.2. For the exchange values of copper and tin in relation to precious metals and the price of grain see Section 7.6.2.

[69] In this field of study the identity of the suppliers of tin to the Central and Eastern Mediterranean networks is particularly controversial. A summary of the arguments in favour of the supply coming from Western Europe, the Taurus Mountains of Anatolia, Uzbekistan and/or Tajikistan or Afghanistan is given in Appendix 3, Section 3.3.1.

[70] Bronze is an alloy of copper with a typical copper-tin proportion for the period of 90% and 10% respectively (Ogden 2000: 154). By the Late Bronze Age, bronze was the metal of choice for weapons, tools and most other metal objects. Other alloys of copper, particularly arsenical copper, will be discussed in Chapter 5, Section 5.1.

[71] For evidence of recycling in Kition in Cyprus see Karageorghis and Kassianidou. 1999: 171-188.

[72] Yalçin, Ü., C. Pulak and R. Slotta. 2005, Bass 1967a: 267-276, and Phelps, W.W, Y.G. Lolos and G. Vechos. 1999..

[73] Discussed further in Section 7.2.3 in Chapter 7.

perhaps staples had to enter the trading network in order to be exchanged for tin, thereby increasing further the overall level of trade. The diversity and quantity of goods exchanged, as demonstrated by the cargoes on the Ulu Burun wreck, shows that production had reached unprecedentedly high levels.[74] The scale of production of both inorganic and organic materials shows that production was in a process of change from part-time cottage industry to an 'industrial scale'.[75] To support this increased level of trading, emporia developed around the Eastern and Central Mediterranean, linking overland trading routes to the maritime trading networks. Relatively peaceful relations within the Eastern Mediterranean following the Hittite-Egyptian peace treaty in 1270 B.C. also encouraged contact and interregional trade.[76]

The economic power of the Egypt in the Eighteenth and early Nineteenth dynasties (1550-1224 B.C.) was at its zenith. It had successfully exploited mineral resources to the north and south of its borders, enabling it to accumulate vast wealth. The annual flooding ensured that, in most years, a harvest surplus was the norm, and this could be exchanged for imported goods or state infrastructure projects. Centuries of controlling a widespread geographically and culturally diverse area had increased the demand for previously rare exotic goods among the Egyptian élite.[77] Egypt's new outward-looking posture not only changed its own internal economic priorities for foreign goods in terms of size and diversity, but another consequence of the demands created was the stimulation of the economies of other regions. The Hittite and Mitanni cultures, each with their own spheres of controlling influence, also provided a similar stimulus for trade, and the Central Mediterranean, too, played a key role by providing an interface between the markets of the Eastern Mediterranean and those of Western and Northern Europe.

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[74] The Ulu Burun wreck and its contribution to the level of trade in the LBA will be discussed further in Chapter 6.

[75] I use the term industrial for manufacturing processes carried out on a large scale of which the majority were state owned who paid the workers rations typically of grain. A clear exception was the textile industry in Egypt which because of the demand for fine cloth required in funerary applications was always produced on a large scale. In the Old and Middle Kingdoms however production centred on a large number of small scale production units generally based in the home using a ground loom. The question of the size of production units is covered in more detail in Chapter 3.

[76] Discussed further in Chapter 7, Section 7.6.3.

[77] Ward 1999: 1031-1034.

The period between 1400 and 1175 B.C. was a nexus of interconnecting cultures exchanging goods and services at an unprecedented level. S. Sherratt succinctly describes this short-lived flowering of international trade at the end of the LBA:

> ".....we can perhaps see it as a late 2nd millennium B.C. version of globalisation." [78]

[78] Sherratt 2000: 89.

# Chapter 3: LBA Agriculture

## 3.1 Introduction

This chapter will investigate the resources in terms of land, manpower, equipment and processes required to support LBA agriculture in Egypt and Cyprus. Food production was needed not only to feed the farmers and their families, but also to feed the non-agrarian workforce and the élite. Without a harvest surplus no non-agrarian activities would be possible. Food production forms the prime basic need of a society in the hierarchy of manpower needs described in the Chapter 2. It has to be met before manpower can be allocated to satisfy any other need as shown in the Schematic 2.1 above.

The economy of the LBA was reliant on food production and so this section examines the vulnerability of LBA agriculture to the influences of the climate. The climate of the Eastern Mediterranean has considerable variation from year to year in temperature, rainfall, and the timings of the seasons. It is not possible to incorporate every micro climatic condition found in the Eastern Mediterranean but two ecologies dominate agricultural practices, hydraulic and dry farming. The first type of ecology is found in those regions dependent on irrigation to achieve reliable arable harvests. Butzer define them as "hydraulic civilisations" and this term will be used hereafter to refer to Mesopotamia which irrigated the land using the Euphrates and the Tigris, and Egypt, with no meaningful rainfall, which utilised the annual inundation of the Nile.[79] The second type of ecology is found in those areas of the Aegean, Cyprus, Central Anatolia, northern Mesopotamia, and southern Levant where the average annual rainfall is below 500mm (Figure 3.1-3.4).[80] For convenience this type of ecology will be referred to hereafter as 'dry farming'. Two regions will be covered in detail for this study: Cyprus representing dry farming and Egypt representing a

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[79] Iraq has a rainfall comparable to semi-arid conditions (Bagdad 140mm and Basra 187 mm). For this thesis it is considered that the precipitation levels had only a second order effect with irrigation dominating agriculture practices in the LBA like today.

[80] Roaf 1990: 22. By convention, dry farming is normally defined as those areas which have a rainfall between 380 mm and 500 mm per annum and some form of irrigation is available. Without irrigation rainfall limits for dry farming lie between 500-750 mm (Widtsoe 1913: 11-14). A working assumption is for satisfactory growth a weight ratio of 1:750 for dry matter produced to rainfall (Widtsoe 1913: 15-18). An important consideration if cereals are to be grown is that the bulk of this rainfall must fall in spring and early summer (Widtsoe 1913: 28-30).

hydraulic civilisation. The results from the analysis of the harvest surplus from this chapter for Cyprus and Egypt will be used in Chapter 7 to determine the scale and nature of their economies.

Measures for the storage of grain in particular helped to even out year to year variations but famine, if not a certainty, was likely if the drought extended for more than two years.[81] In contrast, those years with an optimum rainfall in Cyprus and an optimum rainfall in Ethiopia that fed the Egyptian inundation enabled LBA agriculture to produce large surpluses. It is in these periods of good harvests that wealth could be generated, using surplus food investment in added-value non-agrarian processes such as bronze production and state infrastructure investment.

1. This chapter will quantify for Egypt and Cyprus:
2. The calorie requirements for the population.
3. The weight of crops required to feed the population.
4. The expected yield of crops grown in the LBA.
5. The area of land required to produce the food requirements to feed the population.
6. The resources required (principally manpower) to grow the food required.
7. The size of the harvest surplus available for non-agrarian activities.

An Excel 2003 spreadsheet model was developed (hereafter AGCALC) to replicate the stages outlined above for the LBA.[82] While the algorithms are simple enough, the number of different calculations together with the combination and variation of assumptions are extensive and complex. Standard Excel statistical functions have been used throughout. This spreadsheet quantifies the manpower resources required to support the agrarian sector of the LBA economy by replicating the agricultural production process that has been broken down into its constituent activities as described previously in Section 1.3.1.[83]

[81] Waki 2002: 103-112. This is covered in detail in Section 3.1.2 in Chapter 3 and Section 7.2.1 of Chapter 7.
[82] By convention all demographic studies use a population unit of 100,000. A demographic age profile of the population is used because the total calorie requirement is a function of sex and age. Assumptions used are covered in detail in Section 3.2.2 below.
[83] See earlier discussion on *chaînes opératoire*.

## Sources of evidence

Many of the assumptions used in the model reflecting LBA farming methods, inevitably have large bands of uncertainty. Where the evidence exists and the data can be shown to have a normal distribution, confidence limits around the mean are calculated at the 95% significance level.[84] Classical, Linear B, Mesopotamian, Ugarit, Hittite and Egyptian texts and papyri are used for evidence of harvest yields and agricultural organisation. Egyptian tomb paintings show in great detail the process flow of Egyptian agriculture and are invaluable in identifying the *chaînes opèratoire* of the Egyptian farming cycle. Some of the assumptions used in the agrarian model have no records in the textual, artistic or archaeological record. To fill these gaps assessments are drawn from other disciplines. Archaeo-botanic evidence is used to identify the types of crops grown in the LBA.[85] Similarly archaeo-zoological evidence is used for estimating the size and weight of LBA draft animals and sheep. Ethnographic evidence of traditional farming practices and experimental archaeology findings are used to determine the manpower rates (man-days/hectare) to complete the activities of the *chaînes opèratoire* analysis.[86] West African ethnographic evidence has been used for assessing the work output that can be expected from manual agricultural workers taking into account gender and age.[87] The model is flexible in its design to provide 'what-if' studies and variation in the parameters assist identifying those factors that maximised the harvest surplus in antiquity.

To provide context for the analysis, this chapter will start with a review of the agricultural cycle in antiquity in order to determine the logical order of farming activities throughout the agricultural year. It continues with an overview of how vulnerable LBA agriculture was to short term and medium term changes in climate.

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[84] If it is assumed that the sample of 'n' readings has a normal distribution around its mean of X with a standard deviation of SD, then the 95% confidence range around the mean would indicate that on average 95 times out of a hundred a new reading would be within the range = $X \pm 1.96 \times (SD \div \sqrt{n})$.

[85] For examples of the methodology and the extensive range of information that can be obtained from archaeo-botanical evidence see Haldane 1990: 55-60; Haldane 1993: 348-360 and Clapham and Rowley-Conwy 2006: 6-7 and Murray 2000b: 609-615.

[86] Hereafter 'traditional' will be defined as the farming practices before artificial fertilizers and mechanisation revolutionised agricultural production. Of particular value for evidence of Egyptian farming are Foaden and Fletcher 1908, Richards 1982, Ross 1889, Willcocks 1889 and Willcocks and Beadnell 1904. For Crete and the Aegean see Allbaugh 1953.

[87] McMillan 1988: 104-109.

## 3.1.1 The agricultural cycle in antiquity

This section will examine the agricultural cycle for Cyprus as representative of dry farming regions, and Egypt as representative of agriculture totally dependent on irrigation.

### Cypriot agricultural cycle

No textual evidence exists relating directly to the LBA agricultural cycle of Cyprus in terms of the crops grown, and farming activities within the seasonal cycle. The closest evidence of a dry farming agricultural cycle is in the EIA tablet from Tel Gezer in Israel which has an annual rainfall of the same order as Cyprus.[88] This tablet shows that the practice of growing more than one crop per season gave the advantages of spreading the risk of any one particular crop failing as well as giving variety in the diet at the point of consumption. However there is a price in time and effort to pay for multi-cropping. There are significant disadvantages particularly for small family farms, as they have to split their labour across competing demands for manpower since the crops reach maturity at different times. Each crop requires labour intensive soil preparation, weeding and watering. Understanding the key timings, priorities and manpower allocation within the agricultural cycle is important when quantifying the manpower required and this thesis will use textual, tomb paintings, ethnographic studies, and experimental archaeology as evidence.

The Gezer tablet ca. 900 B.C. found at Tel Gezer has seven intact lines (Figure 3.5).[89] This tablet has been translated by Borowski:

> Line 1: Two months of harvesting (olives). Line 1-2: Two months sowing (cereals), 2 months of late growing (legumes and vegetables). Line 3: One month of hoeing weeds and/or hay production. Line 4: One month harvesting barley. Line 5: One month harvesting (wheat) and

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[88] Rainfall in Israel around the Sea of Galilee varies from 540 mm at the north end to 340 mm at the southern end (Liebowitz and Folk 1980: 27, 40). In Cyprus annual rainfall varies from 400-550 mm depending on the height and proximity to the mountains. Gezer is 30 miles West of Jerusalem near the coast with rainfall levels within the Cypriot rainfall range. The average rainfall of Jerusalem is 540 mm (*Hydrological Yearbook of Israel 1999/2000*. 2003. Accessed 23rd August 2007. Available from http://gwri-ic.technion.ac.il/pdf/wcom/yearbook99-2000.pdf. Jerusalem: State of Israel Ministry of National Infrastructures Water Commission Hydrological Service).

[89] The stratigraphic evidence for the Tel Gezer site where the tablet was found, are imprecise. The date of ca. 900 B.C. has been proposed by Albright 1943a: 16-26, based on archaeological and palaeographic grounds.

measuring (grain). Line 6: Two months cutting grapes. Line 7: One month collecting summer fruits.[90]

The calendar clearly shows that multi-cropping was practiced in the EIA and demonstrates the need to multi-task between one crop and another. The ethnographic evidence of traditional farming methods, crops, and cropping practices in the Eastern Mediterranean up to ca. 1970 A.D. have similarities with the Gezer calendar (representative examples illustrated in Figures 3.6-3.7).[91] This strengthens the case for using ethnographic evidence of modern traditional farming practice, supplemented with experimental archaeology evidence, to increase our understanding of the management of the agricultural cycle in antiquity.

**Ethnographic evidence of the agricultural cycle from dry farming regions**

Halstead and Jones in 1980 made an ethnographic study of two semi-arid Aegean islands, Karpathos and Amorgos.[92] All the villages studied on the islands had limited number of modern agricultural tools. Their objective was to draw parallels with ancient agrarian practices that grew similar crops (wheat, barley, pulses and vetches) and faced with similar climatic conditions. Pulses and vetches were sown in November, barley in November/December, and wheat and lentils in January/February. For winter sowing, the fields were ploughed between November and February.[93] To maximise fertility, fields were left fallow every few years or planted with non-irrigated summer crops. Grass covered fallow land brought back into cultivation required three ploughings between March and May to prepare the soil for sowing. Even land cultivated the previous year required three ploughings to control weeds, though it did not take as much time as preparing fallow land. Shallow ploughing was required in March, a deeper ploughing at right angles in April and a final shallow ploughing prior to sowing in May. The use of sledges fitted with flints to thresh cereals was a common practice in Cyprus and across other areas of the

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[90] Translated and analysed by Borowski 1987: 38; table 3. Agro-ethnographic study of early 20th century A.D. Palestinian agriculture at el-Qubēbe and el-Ruwēr implies that this activity refers to the weeding the fields allocated to winter sown crops (Dalman 1932: 216-217). Borowski 1987: 38; table 3. Line 3 is interpreted by Borowski as hay/fodder production rather than weeding of crops.
[91] Ataman 1999: 211-220, Forbes 1992: 13-19, and Halstead 1987a: 53-70, and Halstead and Jones 1989: 41-55.
[92] Halstead and Jones 1989: 41-55.
[93] Halstead and Jones 1989: 47.

Mediterranean.[94] The ethnographic evidence from Cyprus suggests that from a climatic and methodological point of view traditional farming follows the same cycle and uses the same approach to maintain fertility.[95] It is reasonable to assume that when faced with the same climatic conditions the options were limited and we can expect a common approach to farming in antiquity.

### The Egyptian agricultural cycle

In Egypt the agricultural cycle is dominated by the Nile inundation and only marginally affected by the seasons. The importance of the inundation to the agricultural cycle is clear from the names of the three divisions of their calendar: *Akhet* (inundation July to September), *Peret* (growing) and *Shemw* (drought).[96] If the inundation was low in a given year little could be done within the cycle to compensate. For average inundation heights or better, the harvest cycle would follow the same pattern that had been in place since the pre-Dynastic period.

## 3.1.2 The vulnerability of LBA harvests to the climate

### Cypriot farming

While it is generally accepted that annual rainfall above 380 mm is required for successful dry farming, it is possible for limited success with precipitations as low as 240 mm, or in times of drought.[97] However, at this level other factors must be managed to ensure a viable grain harvest. The inter-annual variability of the rainfall must be within a range ±37% of the average rainfall, and the monthly rainfall in December to March must exceed 25mm for each month.[98] Even in summers with rainfall greater than 300mm, some form of irrigation is required at the height of the summer, usually sourced from underground springs. A run of 2-3 concurrent seasons of low precipitations within the range 200-150 mm leads to a drop in the water table, with consequent drying up of streams.[99]

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[94] Hornell 1930: 135-139, Myres 1931: 32, and Whittaker 2000: 62-69.
[95] Christodoulou, Rowson and Sealy 1959, Knapp 1990b: 147-176, and Yerks 2000: 20-34.
[96] Kemp 1991: 10.
[97] Arnon 1972: 463
[98] Lockwood 1985: 129-130. A 25mm monthly average is not adequate for a successful harvest.
[99] Halstead 1989: 74.

The climate of the Aegean and north-eastern Mediterranean can be characterised as having two seasons; October to the end of March is cold with high precipitation levels and April through to September is hot and dry. Spring and autumn are less marked than in Northern Europe. The mountains of Greece and Crete can have a local influence on precipitation levels when the moisture carrying air from the central Mediterranean Sea meets elevated ground. For example, the average rainfall for Athens is 371 mm but in the lee of the mountain chain in the central part of mainland Greece and Crete it can rise to 800-1200 mm (see again Figures 3.1-3.4).[100] With levels of precipitation in most parts of mainland Greece, Anatolia, the Aegean, and Cyprus lying within the range 350-600mm per annum, wheat, barley, pulses, olives, grapes, and legumes are grown successfully today and in all probability in antiquity as well.[101]

The climate of southern Levant is typically Mediterranean with mild, rainy winters and hot summers. Modern precipitation levels in the southern Levant lie in the range 250 mm to 500 mm and in the northern Levant 600-800 mm (see again Figure 3.1).[102] The climate enabled cereals to be grown by dry farming methods and by the LBA period olives and wine were major exports.[103]

The modern meteorology pattern for the Aegean and north-eastern Mediterranean shows that drought years frequently come in clusters of up to three years which would stress the agrarian process to its limit. The 2-3 year drought cycles occur when a trough of low pressure in the Mediterranean moves west of its normal position. This situation creates a higher than normal high pressure system over Turkey which moves the flow of rain storms that normally fall on Greece into northern Europe. The net result is higher rainfall in northern Europe, and longer drier summers in the Mediterranean.[104] This metrological phenomenon is called a 'three wave expanded circumpolar vortex' and has occurred as recently as the 1950's A.D. The results for 1954-1955 show that 60% less precipitation fell in Northern Greece and 40% less in

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[100] Isager and Skydsgaard 1992: 10-11.
[101] Halstead 1980: 266 and Halstead 1992: 107-109, Table 1. In the LBA the main grain crops were einkorn, emmer, spelt, and *T. durem* wheat; six row barley, and common millet. The most common pulses grown were bitter vetch and lentils.
[102] Rainfall is greatest near the coast with modern Beirut having an annual rainfall of 860mm.
[103] Fall 1998: 118 and Stager 1985: 172-185.
[104] Willett 1953:51-83.

the Peloponnese, Crete and Turkey.[105] Carpenter, Bryson, Lamb and Donley suggest that just such an event occurred in ca.1200 B.C. and the consequent series of droughts was the major contribution to the decline of the Mycenaean culture.[106] Not all climatologists accept this, arguing there are too many metrological variables to say with confidence that any particular historical event in the past was due to climate change.[107]

The analysis of 1000 years of tree-ring data for Morocco show mini-drought cycles occurring at regular intervals in the Mediterranean.[108] Morocco had a similar climate to the Bronze Age Eastern Mediterranean dry-farming areas and applying this data the tree-ring data shows that these clusters of drought could be expected at least once or twice every century.[109] Moody's study of the Aegean and north eastern Mediterranean in the LBA supports this view. Her analysis of pollen counts, stable-isotope studies of deep sea cores, speleothems (secondary mineral deposit formed in caves), tufa, and tree-ring studies, from Israel, Turkey, Italy, Crete, and Spain indicates that the climate for the period 1650-1400 B.C. had cooler winters with increased rainfall, probably resulting from the Santorini eruption. In the period 1300-1200 B.C. both the summer and winter temperatures increased to levels above those expected in the Aegean today. A change occurred between 1200-1150 B.C., with colder and drier conditions in the Aegean but hotter and drier conditions in the Levant compared with the previous period.[110]

**The management of drought in dry farming areas**

Extensive terraces were used in the island of Pseira, Crete, Cyprus, Mainland Greece, and the hills in the Negev Desert in Israel to prevent the erosion of soil from winter rains. On the island of Pseira two Bronze Age dams were built across the ravines and it is believed that they were used for irrigation, animal and domestic drinking purposes. Each dam held between 500-600 $m^3$ of water in the catchment area behind the dam. An additional benefit to farmers was the collection of soil washed down

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[105] Bryson, Lamb and Donley 1974: 48, Figure 1.
[106] Carpenter 1966: 61 and Bryson, Lamb and Donley 1974: 46-50.
[107] Desborough 1968: 111-114 and Wright 1968: 123-127.
[108] Stockton and Meko 1990: 1-26 particularly Figure 1.15.
[109] Wilkinson 1994: 499 and
[110] Moody 2005: 443-465 and particularly 462-465.

from the upper levels which was periodically dug out of the catchment area and put back on the nearby terraces.[111] In the Levant, cisterns were built to store water for both domestic use and irrigation purposes.[112] In the hills in the Negev Desert, cisterns were built to collect runoff rainfall, on mountain and hill slopes, from rainstorms that occur mainly between October and May, through channels up to one km in length.[113] The cisterns of an EIA settlement near modern Beersheba-Elath had eight cisterns, circular in shape dug into the marl clay and lined with stones. They are about 4 m deep and vary from 10-100 $m^3$ in capacity.[114]

These two examples highlight the ability of ancient farmers to find solutions to sustain communities with food and water.

**The management of excessive winter rains**

In dry farming, flood water from the rivers carried alluvial deposits to coastal plains and flat inland basins and provided perfect conditions for agriculture.[115] Too much rain in winter can however cause longer lasting problems for farmers than droughts. Excessive rain on sloping rocky ground can wash away the limited top soil to below the threshold depth of 0.3m required for adequate root growth of cereals and pulses.[116] Successive wet winters can wash out soil fines less than 0.1 mm, which can permanently alter the structure and fertility of the soil even if the threshold depth is retained (Figure 3.8).[117] Trace elements and organisms essential for growth and disease resistance are leached out of the soil. The exposed stony ground encourages rain to soak away faster which in turn exacerbates the effects of the summer droughts in following years.

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[111] Betancourt and Simpson 1992: 47-54. No irrigation channels were found but the large number of amphora suggests that the water was carried up to the terraces. Analysis of pottery sherds shows this practice ceased in the LM1 period.
[112] Evenari, Aharoni and Tadmore 1958: 231-257 and Evenari *et al* 1971.
[113] Evenari, Aharoni and Tadmore 1958: 233-234, 238.
[114] Evenari, Aharoni and Tadmore 1958: 243.
[115] Arnon 1972, Halstead 1994: 196 and Zangger 1992: 14-15.
[116] Lampurlanés and Cantero-Martínez 2003: 526-536 study of the effects of fallow and tillage on soil physical properties of soil bulk density and root penetration shows that even without ploughing, barley could provide grow adequately in a soil depth of 0.3m. Tiedeman *et al* 1998: 288 citing ethnographic evidence from Morocco indicates a similar depth required to grow barley and legume fodder.
[117] Anthoni, J.F. 2000. *Soil Erosion and Conservation.* Accessed 3rd April 2007. Available from www.seafriends.org.nz/enviro/soil/erosion.htm.

For healthy root growth cereals and pulses require air gaps between the interstices of the soil particles and water-logging from flooding can cause rot and disease.[118] Ploughing in wet conditions using heavy oxen creates a 'plough pan' below the surface. The pan prevents water drainage and if repeated over successive wet winters, the plough pan reaches a critical depth making the land water logged every winter. At the same time the plough pan causes the limited annual rainfall to run off because the top 20 cms is waterlogged. This progressively lowers the water table aggravating the problems of meeting the demand for water in the growing season.[119]

In summary excessive rain, particularly cloudbursts in winter, created as many challenges for the ancient farmer as managing infrequent rain patterns in summer.

## Egypt's climate

Egypt's climate was atypical compared with the other regions in the eastern Mediterranean. The defining difference is that the average rainfall is so low: 220 mm on the Mediterranean coast, 20.5 at Giza, 3.5 mm at Aswan, and 1.4-5.3 mm along the Nile Valley between these two points. Without the annual inundation of the Nile, agriculture could not be sustained.[120] The inundation carried with it fertile silt from the Ethiopian highlands that the Egyptians called the 'Blood of Osiris', which was deposited over the flooded fields.[121] The height of the inundation is dependent on the rainfall in Ethiopia and Uganda. Three sources fed the Nile: the Blue Nile which provided 83% of the flow, the White Nile provided 16% of the flow and the River Atbara which contributed an additional 1% (Figure 3.9). The flow of the Blue Nile hardly varies as its source is Lake Tanganyika which is fed from the rainfall in the

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[118] Watson, Lapins and Barron 1976: 114-121. Experiments maintaining a 80% saturation level in the first six weeks of growth barley and wheat resulted in a drop in yield of 39% and 53% respectively.
[119] FAO 1994. FAO is the Food and Agricultural Organisation of the United Nations.
[120] Foaden and Fletcher 1908. The temperature averages for Giza and Aswan were calculated over a twenty year period for the period 1885-1905. For a modern analysis of mean Egyptian temperatures particularly for the Nile Valley see Zahran and Willis 1992: 308.
[121] The amount of silt carried can be considerable when the Nile is at full flood. Measurements in 1908 show that the Ruweina Canal carried 1380 gms/m$^3$. This was made up of 90 gms/m$^3$ of soluble matter, 53 gms/m$^3$ of fine sand, 204 gms/m$^3$ of silt, 407 gms/m$^3$ of fine silt, and 627 gms/m$^3$ of clay (Hughes 1911: 35). It is estimated that the silt carried by the whole inundation amounted to 57 million tons (Hassan 1997: 59). This represents on average a rate of deposit of 6.5 tons/feddan (34667 kg/ha) which represents an increase in soil depth of 1 mm per inundation (Foaden and Fletcher 1908: 227). Nile mud is rich in potash but poor in nitrogen. Without regular crops of beans and/or berseem to naturally fix nitrogen, the Egyptian soil would soon become impoverished (Foaden and Fletcher 1908: 230-232). The high potash content of Pharaonic mud bricks explains why modern Egyptian farmers use them as a source of fertilizer.

Ethiopian highlands. The vast capacity of Lake Tanganyika evens out any variation in rainfall giving a consistent discharge into the Blue Nile. Fluctuations in the rainfall in Uganda which feeds the White Nile, dictate the height of the inundation.[122] A low inundation caused by a dry season in Uganda could be exacerbated when the River Atbara ran dry in summer and this was a frequent occurrence. Egypt was not immune to periods of famine caused by a run of low inundations as attested by the scenes from the causeway at the mortuary temple of Wenis at Saqqara and the tomb paintings of Ukh-hotep at Meir (Figures 3.10-3.11). The textual and epigraphic evidence of failed harvests are silent in the New Kingdom. Nevertheless rainfall always varies around the mean and the rains in Uganda, feeding the Nile, would be no exception and would lead to high and low inundations. This thesis postulates that the shaduf water lifting technology used in the New Kingdom would not be able to compensate for the detrimental effects of a low inundation and that therefore poor harvests were inevitable.[123]

The Nile inundation varies not only year on year, but over time the average height of the inundation varies. Figure 3.12 plots the averages of consecutive centuries' differences between the high and low levels of the annual inundation. The data was measured on the Nilometer at Rhoda Island near Cairo and shows that over 13 centuries the difference was 1.2 m. The consequences of this change in average inundation heights would have significant impact on the manpower effort required to lift water by shaduf or the maintenance of the basin irrigation system is significant.[124]

A particularly high or late inundation which affected the onset of ploughing and sowing (normally October and November) could cause the harvest to be delayed by 3-4 months to late May-July. A delay in sowing exposed the cereals as they approached maturity to the dry hot 'Khamsin winds' which lowered crop yields through desiccation.[125] Another problem associated with long duration of lying water was that it encouraged parasite and fungal infections resulting in lower crop yields. If the river flowed too fast due to excessively high floods, the levees would be eroded

[122] Brewer and Teeter 1999: 22-25.
[123] The evidence is examined further in Section 3.4.6.
[124] Tabular data taken from Willcocks and Kemeid 1904: 50.
[125] Willcocks 1889: 304. The Khasim winds occur between March and early June, when a weak depressions draw hot sand-laden air from the Sahara towards the coast.

causing the river to violently change direction. This washed away field systems and villages in its wake and happened numerous times throughout Egypt's long history.[126] Oxen and donkeys were also in danger from flash floods if they could not be moved in time to higher ground. Contemporary observations of the excessive floods in 1818 A.D. and 1878 A.D. demonstrate the level of devastation inflicted on agricultural communities when the Nile breaks its banks during a high inundation.[127] Problems of too low and too high inundation in Egypt are well summarised by Pliny:

> "...... an average rise of one of the 16 cubits (24 ft). A smaller volume of water does not irrigate all localities, and a larger one by retiring too slowly retards agriculture..... The province takes careful note of both extremes; in a rise of 12 cubits (18 ft) it senses famine, and even one of 14 cubits (19.5 ft) it begins to feel hungry, by 15 cubits (22.5 ft) complete confidence and 16 cubits (24 ft) delight.[128]

## Summary

Egypt had the most favourable climate of any region in the Eastern Mediterranean and could consistently produce large harvest surpluses. The arable geographic footprint of Egyptian Nile Valley, 600 miles by 1-15 miles wide either side of the Nile, made the transport of harvest surplus an easy proposition. Evidence for the rapid transport and effective storage of grain from the harvest, and the impact of failed harvests due to inadequate rainfall or too much rainfall falling outside of its borders will also be investigated in Chapter 7, Section 7.2.1.

The rainfall of the dry farming regions in the LBA Eastern Mediterranean did vary significantly from year to year and farmers would have had to adapt their farming strategies to manage this variation. Despite these rainfall fluctuations the evidence points to the probability that a wide range of cereals, pulses, fruits, and vegetables could be grown with careful management of water supplies.

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[126] Hassan 1997: 51-74. The Nile has moved across the Nile Valley at a rate of 2-3km per 1000 years (Hillier, Bunbury and Graham 2007: 1-2, Figure 1. Forthcoming, accepted 7th September 2006 for publication in the Journal of Archaeological Science 2007, Volume 35, in press.)

[127] Willcocks 1889: 187-188 and Willcocks and Beadnell 1904: 71.

[128] Pliny, *Nat Hist.* 5.58. One extreme case is noted by Pliny that in the year 48 B.C. the Nile only rose 5 cubits. This equates to 2.25 m assuming the Roman 'natural cubit' equalled 0.45 m.

## 3.2 Calorie requirements

The objective of this section is to estimate not only the number of calories that had to be produced from the harvest to feed the population but also the variety, and proportions of the foods eaten in Egypt and Cyprus in the LBA needed to maintain a healthy lifestyle. This analysis of the diet will be used in Section 3.2.5 below to determine the weight of the crops required to be grown to meet the calorie requirement of the LBA diet. Section 3.2.6 below will examine the textual, ethnographic, and experimental archaeology evidence and estimate the expected yields of the main crops grown in the LBA. Section 3.3 estimates the area of land required to grow this weight of crops. Finally the manpower required to work on the land to produce this weight of crops will be estimated in Section 3.4.

The textual evidence of Egyptian, Mesopotamian and Aegean Linear B texts and Egyptian tomb art provide a useful starting point to investigate LBA food production, and processing. To attempt to understand the full complexities of an ancient diet, this thesis takes a multi-disciplined approach using the findings from food residues, ethnographic analogies of farming and food preparation practices, experimental archaeology, skeletal and dental evidence and contemporary dietary/nutrition requirements (Figure 3.13).[129] Although Egyptian tomb paintings are often cited as evidence for agricultural products and processes, care has to be taken in the interpretation of the scenes as they reflect the world of the élite. Many of the scenes are representative of cult activities such as the banquet and offering scenes and which show the deceased in an idealised afterlife. In spite of this we can use these scenes to get some insight into what was consumed by the élite but not the proportion of the different crops that made up the diet.

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[129] Gilbert and Mielke 1985: i-xiii summarise this multi-disciplined approach showing how human and skeletal material can be linked to both archaeological and ethnographic data and from them identify the ancient diet. The major studies used in this paper to understand regional variations in the diet of the Central and Eastern Mediterranean are, for the Aegean and the Levant Borowski 1987, 2004: 96-107, Dennell 1979: 121-135, Gallant 1991, Halstead 1996: 20-42, Halstead and Barrett 2005, Megaloudi 2006, Palmer 2003: 125-138, Riley 1999, Sarpaki 1992: 61-76 and Tzedakis and Martlew 1999. For Egypt, Darby, Ghalioungui and Grivetti 1977 still remains a good starting point to study the Egyptian diet. For detailed multidiscipline studies of the Egyptian diet see Miller 1991: 257-269, Murray 2000a: 505-536, Murray, Boulton and Heron 2000c: 577-608 and Murray 2000b: 609-655 and Serpico 2000: 390-429; Serpico 2004: 96-120. An excellent cross-cultural overview of the ancient diet is found in Brothwell and Brothwell 1998.

The analysis and assumptions used in AGCALC associated with determining the annual calorie requirement to feed the population of Egypt and Cyprus are found in Reports 3.2-3.8e.

## 3.2.1 Annual calorie requirement

The Farming and Agriculture Organisation has published recommended the calorie levels required by workers to stay healthy while undertaking a range of activities.[130] This data has been collated by the FAO into four categories: body weight, sex, age and the nature of work carried out by the individual. Some gaps exist across some of the variables and these have been supplemented from other sources.[131] The FAO recommendations reflect active manual workers working on the land using hand tools. A simplified summary used in AGCALC banded by age group is shown below.

| Demographic age bands | Manual lifestyles Calorie requirement kcals/day | | Sedentary lifestyles Calorie requirement kcals/day | |
|---|---|---|---|---|
| | Male | Female | Male | Female |
| Children weaned in the second year | - | - | - | - |
| Children 3 years old | 1,000 | 1,000 | 1,000 | 1,000 |
| Children under 4- 6 years old | 1,878 | 1,790 | 1,455 | 1,333 |
| Children under 7-9 years old | 2,190 | 2,110 | 1,852 | 1,655 |
| Adolescents 10-12 years old | 2,600 | 2,600 | 2,127 | 1,890 |
| Adolescents 13-15 years old | 3,237 | 3,037 | 2,557 | 2,272 |
| 16-19 | 3,425 | 3,070 | 2,802 | 2,343 |
| 20-39 | 3,750 | 3,000 | 2,683 | 2,083 |
| 40-49 | 2,700 | 2,800 | 2,600 | 2,117 |
| 50-59 | 2,400 | 2,150 | 2,600 | 2,117 |
| 60-69 | 2,250 | 1,947 | 2,200 | 2,117 |
| 70+ | 2,200 | 1,900 | 2,200 | 1,883 |

**Table 3.1: Summary of the daily calorie requirement in kcals/day, for males and females**

## 3.2.2 The energy requirement to feed 100,000 people

The purpose of this section is to estimate the total energy required (million kcals/year) to feed a population sample of 100,000 men, women, and children.[132] The

130 The Farming and Agriculture Organisation is part of the World Health Organisation of the United Nations, Washington D.C. (hereafter FAO and WHO)

131 FAO 1973. Energy and Protein Requirements, FAO Nutrition Meetings Report Series No. 52 and WHO 1973. Technical Report Series No. 522. Dennell 1979: 125, table 3, Foxhall and Forbes 1982: 49, footnote 26 have used the FAO 1973 document as their base data. Gallant 1991: 73, table 4.5 has based his analysis on the findings of Clawson, Alexander and Landsberg 1971: 101, 156-7 and Allbaugh 1953: 106-112, table 9. This analysis assumes that children are weaned in the second year based on ethnographic evidence of the third world. The World Health Organisation has shown that breast feeding does delay on average conception for up to six months. See Szpakowska 2008: 213-214 for evidence relating to breastfeeding as a form contraception.

132 By convention it is customary in demographic studies to use a population size of 100,000 and this unit will be used throughout this agrarian model (Parkin 1992: 75). It is also the convention that

first stage is to estimate the number of individuals within the age bands (hereafter demographic age profile) given in the first column of Table 3.1 (Reports 3.6a-3.7f in AGCALC). These age cohorts are multiplied by their associated daily calorie requirements (columns 2-5 of Table 3.1), and then multiplied by 365 to get the annual calorie requirement that had to be supplied by the annual harvest to ensure the population remained healthy.

Coale-Demeny, Frier, Parkin, and Scheidel have made important contributions to estimating the demographic age profile of populations in antiquity.[133] Coale-Demeny developed life tables based on evidence from Mauritius between the years 1942-1946 A.D.[134] Frier developed a Roman life expectancy model based on the 'Ulpian life table', which was used for computing tax for the *alimenta* and for *usufructs*.[135] Parkin has reservations on the whole validity of using the Ulpian life tables as he considers them unrepresentative of the life expectancy of the general populace found in antiquity. Parkin recommended that the Coale-Demeny Model 3 West demographic model should be used for all age groups as it is more representative of life expectancy of those aged one to five.[136] For comparisons between the Frier's and Coale-Demeny models (Figure 3.14). Scheidel's work is more concerned with absolute population levels in antiquity which he considers were much lower than the current consensus amongst scholars, due to pandemic plagues that will be discussed in Section 5.3.1 in Chapter 5. The model chosen for this study is the Coale-Demeny

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demographic studies are zero index based (Parkin 1992: 75-78). For example starting point of demographic studies is $l_0$ =100,000 i.e. 100,000 babies that successfully survived child birth. Demographic studies follow these 100,000 individuals throughout their lives until they are all dead. Explanations and examples of the demographic algorithms used in the model are given in Report 3.6a.

[133] Coale, Demeny and Vaughan 1983, Frier 1982: 213-251; Frier 2000: 787-812, Parkin 1992; Parkin 2003 and Scheidel 1982: 1-26; Scheidel 1996; Scheidel 2001b.

[134] Frier's own model modifies Ulpian life table to take into account life expectancy between the ages 0-15. For this age range he uses the Coale-Demeny Model West, level 2 model (Frier 1982: 227, chart 2 and Coale, Demeny and Vaughan 1983). It should be noted that there was a better correlation for females than males (Frier 1982: 234, table 3).

[135] The alimenta were trusts for the maintenance of poor or orphaned children in Roman Italy. Usufruct is the legal right to use and derive profit from property belonging to some one else. Ulpian had presented tables which were used to compute tax for alimenta and also for usufructs. The former involved determining the age of the legatee and second figure a number of years, which declined as the legatee's age increased. This second figure serves as the multiplicand in computing the amount of tax to be paid for a given tax rate (Frier 1982: 217). The Ulpian's life table and customary life tables are shown plotted in Frier 1982: 218, chart 1.

[136] Parkin gives a comprehensive overview of the statistics used in demographic studies and the background, methodology and assumptions of the Coale-Demeny demographic model and why he believes they should be used for studies of ancient populations (Parkin 1992: 67-133). For a contra position of the use of the Coale-Demeny demographic models see Scheidel 2001b: 1-26.

Model 3 West as it is more applicable to agrarian demographic profiles than Frier's, which draws on urban evidence.[137] The estimates for the demographic age bands calculated in AGCALC are tabulated in the table below.

| | Coale-Demeny | Frier's model |
|---|---|---|
| Demographic age bands | Survivors | Survivors |
| Children under 3 years old | 15,080 | 16,700 |
| Children under 4-9 years old | 14,840 | 16,890 |
| Adolescents 10-15 years old | 10,740 | 12,070 |
| Adults 16-50 years old | 45,570 | 45,670 |
| Adults 50-60 years old | 8,200 | 5,630 |
| Elderly 60+ | 5,570 | 3,040 |
| Total | 100,000 | 100,000 |

**Table 3.2: Survivors collated by demographic age band using the Coale-Demeny Model 3 West**

## Calorie requirements

While the majority of the population was involved in heavy manual work, a minority would be involved in a sedentary lifestyle requiring fewer calories (this would include amongst others; scribes, cloth makers, the élite, and the aged). For this segment of the population I have used the calorie requirements developed by Jongman.[138] The resulting calorie requirement matrix used in this thesis for calorie requirements is given in Report 3.8a in AGCALC for manual workers and Report 3.8b in AGCALC for the sedentary. For this study it has been assumed that 75% of the population was involved in manual work and 25% of the population was involved in sedentary work.[139] The resulting total calorie requirement taking into account manual and sedentary workforce is given in the tables below.[140]

| Demographic age band | Total Million kcals required/yr/100000 people | |
|---|---|---|
| | Active | Sedentary |
| Children under 3 years old | 3,222 | 1,074 |
| Children under 4-9 years old | 7,934 | 2,072 |
| Adolescents 10-15 years old | 8,435 | 2,168 |
| Adults 16-50 years old | 40,020 | 10,000 |
| Elderly over 50 years old | 8,291 | 2,850 |
| Totals | 67,902 | 18,163 |

**Table 3.3: Active and sedentary energy requirements million kcals/yr/100,000 collated by age**

[137] AGCALC has the flexibility to use either demographic model by entering 1 or 2 in cell K1. Enter 1 to use the Frier model or 2 to use the Coale-Demeny demographic model respectively. The assumption used for infants under 3 years old on average are breast fed, therefore for infants aged 1-3 only one third require feeding from land produce.

[138] Jongman 2007: 599, Table 22.1.

[139] This can only be an approximation which has been based on the assessment of the other sectors of the summarised in Report 3.1e in AGCALC.

[140] For full analysis see Reports 3.7a-3.8f in AGCALC. The assumption used for infants under 3 years old is that on average they are breast fed, therefore for infants aged 1-3 only one third require feeding from land produce.

| Physical versus sedentary lifestyles | Total Million kcals required/yr/100000 people | |
|---|---|---|
| | Percentage split | Energy |
| Population with high physical labour lifestyles | 75 | 67,902 |
| Population with sedentary lifestyles | 25 | 18,163 |
| **Total energy required** | **100** | **86,065** |

**Table 3.4: Resultant total energy requirements million kcals/yr/100,000 population after taking into account active and sedentary life styles**

In summary, the model has estimated that 86,065 million kcals per annum were required to feed 100,000 people per year. Sections 3.2.3-3.2.4 following will estimate the proportions of crops grown in the LBA that make up this calorie requirement. The order of these sections reflects their contribution to the LBA diet in terms of energy.

## 3.2.3 The LBA diet

### Cereals

The highest proportion of calories in the LBA came from cereals. The first evidence for the deliberate cultivation of domesticated cereal dates to between the ninth and eighth millennium in the Levant.[141] Cereals evolved from wild grasses that formed hybrids which delivered greater yields.[142] Farmers improved the yield of the cereals over time by deliberately selecting those characteristics that maximised yield and reduced the effort to grow them.[143] Unlike animals, where any deviation creates abnormalities that can be a major impediment or even prove lethal, plants allow chromosome doubling and with this flexibility different species and different generations can cross pollinate. One possible evolutionary route for the domestication of wheat is given in Figure 3.15.[144]

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[141] Smith 1995: 21.

[142] Cereals can be divided into three groups according to the number of chromosomes but the majority of cereal plants are diploid possessing two sets of chromosomes.

[143] Feldman, Lupton and Millar 1995: 184-192 and Murray 2000a: 505, Figure 21.1. By selecting hybrids that stood erect and ripened at the same time, two problems were overcome. The plants were able to withstand weed competition and the time spent harvesting was minimised. In addition, choosing seed corn from hybrids with the largest number of fertile florets, increased yield. Similarly choosing the seed corn from plants that had less awn (bristle-like spikelets) and husks minimised the time to thresh the cereal.

[144] Wheat can be categorised into three main groups: the 14-chromosome group that includes the wild and cultivated einkorn, 28-chromosome group that includes the wild and cultivated emmer and durum and the 42-chromosome group that includes the wild and cultivated bread wheat (Roaf 1990: 29).

Archaeo-botanic evidence suggests that emmer wheat (Triticum dicoccum) and barley (Hordeum vulgare) were the most common domesticated cereals grown in the LBA.[145] Barley, with its greater capacity to withstand drought, is still dominant today in dry farming agriculture of Iraq, Syria and Iran.[146] Emmer wheat, in contrast, grows best in areas with an annual rainfall of 600-760 mm of rainfall.[147] It is reasonable to assume that in the LBA areas of low rainfall or periods of prolonged drought, barley would be grown extensively.[148]

## Evidence for the types of cereal grown in Egypt

The archaeo-botanical record from Egypt shows that both two-row and six-row barley was grown in Egypt but significantly more of the latter.[149] Barley can also be grown in dry and low fertile soils and is able to cope with higher levels of salinity caused by poor control of flood water.[150] The record also shows barley was used extensively as fodder.[151] The proportion of barley to wheat found in the archaeo-botanic record does not necessarily indicate the ratios for human consumption. Traces of barley in charred contexts could have come from burnt animal dung.[152]

New Kingdom Egypt is particularly elusive as to the information on mix of barley to wheat. Tomb paintings do not differentiate between wheat and barley.[153] Textual evidence can be confusing as there are seven words to describe grain in general terms

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[145] Barley had two common forms: Hordeum vulgare hexastichum was a six-rowed form of barley grown in winter and used in the human diet and for fodder, Hordeum disticham was two-rowed barley normally grown in spring and was the preferred species to make beer.
[146] Zohary and Hopf 2000: 55. In Syria it is possible even in extreme drought conditions of less than 133 mm of rainfall, to cultivate barley with a mean yield of 350 kg/ha.
[147] Zaccagnini 1975: 217
[148] Renfrew 1985a: 185. Emmer wheat *Triticum dicoccum* has been identified at the rubbish dumps of the Workmen's Village at Amarna as well as Barley *Hordeum vulgare.*
[149] Vartavan and Amoros 1997: 127-128.
[150] Foaden and Fletcher 1910: 438 and Zohary and Hopf 2000: 55.
[151] This is known from archaeo-botanic studies of charred animal dung used as fuel in Pharaonic Egypt (Murray 1993: 165-168). Various bio molecular components preserved in domesticated animal bones are used for dietary reconstruction of their foddering and foraging behaviours. Bulk stable isotope value analysis of bone collagen and apatite combined with compound specific stable isotope values of the collagenous amino acids (essential and non-essential) of sheep and goat remains from the Nubian site of Qasr Ibrim show that they were fed both barley and sorghum across all agricultural periods from 700 B.C.-1800 A.D. (Copley *et al* 2004:1284). It is interesting to speculate that perhaps barley may have been fed to Egyptian sheep and goats as well as cattle for the period under study, possibly reflecting the lack of natural fodder for the animals in Upper Egypt.
[152] Murray 1993: 165-166 and Murray 2000a: 513.
[153] Kemp 1994: 145.

and only three can be interpreted as wheat (Figure 3.16).[154] Roman, Greek and later travellers to Egypt had their own terms to describe grain which only adds to the confusion. The most common of the seven words for grain are *it, sšrw, sš,* and *npr,* and of these, Darby suggests that *it* represented barley.[155] Even the three words for wheat; *bdt, bti, swt,* are ambiguous as Ramesside scribes wrote *bdt* (wheat) in red ink and *it* (barley) in black ink.[156] Kees believes wheat (type unspecified) was not in common usage until some time in the New Kingdom.[157] Lloyd goes farther saying it was only at the end of the New Kingdom that emmer wheat as a crop was as important as hulled barley.[158] The recent archaeo-botanical finds at Qasr Ibrim in Egyptian Nubia and Upper and Lower Egypt show that by the ninth century B.C. emmer wheat was as important a crop as hulled barley.[159] Egyptian ration dockets found in the Middle Kingdom fort of Uronarti indicate that the soldiers' rations for 10 days comprised of 2/3 *ḥeqat* of northern barley and 1 *ḥeqat* of wheat which equates to 2,136 kcals/day.[160]

On the balance of the limited evidence it has been assumed that barley was the main cereal cultivated in New Kingdom Egypt. Barley had many advantages for the Egyptians as it was tolerant of salt, required lower man-days/hectare to grow and was suitable for beer production. Based on this evidence the model has assumed the contribution of calories in the Egyptian diet was 75.3 million kcals/yr/100000 population, supplied by barley (56.5 million kcals/yr/100000 population) and wheat (18.8 million kcals/yr/100000 population), split in the ratio 75% barley and 25% wheat.[161]

### Cereal requirement to make Egyptian beer

Most textual references, models, and tomb paintings, imply that beer was the drink of choice for the non-élite.[162] Archaeo-botanical evidence from the workmen's villages

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[154] Darby, Ghalioungui and Grivetti 1977: 482.
[155] After Darby, Ghalioungui and Grivetti 1977: 457. The Gardiner codes for these hieroglyphs are F., 32; F., 428; F., 270, and F., 270.
[156] Gardiner 1947: 222.
[157] Kees 1961: 74.
[158] Lloyd 1983: 183.
[159] Clapham and Rowley-Conwy 2006: 6-7.
[160] Miller 1991: 257-258.
[161] See Reports 3.9c-3.9d for analysis and assumptions.
[162] For sources of evidence and an informative description of the Egyptian brewing process see Samuel 2000: 537-557.

of Amarna and Deir el-Medina suggests that barley was the cereal of choice for brewing.[163] For the model it is assumed that the 5.1% of the total calories were from beer and 0.3% from wine for the élite.[164] New Kingdom tomb models show that these could be large centres of production that reflect a high demand.[165] The total barley hectarage for barley production was 19,854 hectares/100,000 people.[166] The barley hectarage dedicated to supply 100,000 people with beer would have been 1,787 ha.[167]

## Evidence for cereals grown in dry farming regions

At Mycenae, emmer and einkorn wheat, barley, bitter vetch and fava beans have all been found.[168] The archaeo-botanical evidence from Mainland Greece shows that emmer wheat, einkorn wheat, spelt and durum were all grown in the LBA.[169] Einkorn wheat dominated in northern Greece and emmer in southern Greece. One exception is the site of Assiros Toumba (1350 B.C.) where durum wheat was the dominant crop.[170] Excavations at Tel Yin'am in Canaan have produced 59,086 samples of plant remains. Approximately 57,000 were land crops of wheat (*Triticum* sp. L.), barley (*Hordeum* sp. L.) and vetch (*Vicia* sp. L.).[171] The proportions of the seed assemblage were 96.22%, 3.23% and 0.55% respectively (Figure 3.17). Within the remaining 2000+ samples, olive stones, lentils, flax and grape seeds were identified. Interpretation of these findings must take into account that the majority of plant remains were found within building 1 of Tel Yin'am which could have belonged to a member of the élite, and is therefore not representative of the whole

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[163] See Samuel 2000: 539-541, 547. for discussion of the evidence that emmer wheat was sometimes used for brewing. Grains of wheat (probably emmer) were identified from the microscopy of brewing residues in large vats found at Abydos and Hierakonpolis. Samuel using evidence from these and other tests, archaeological evidence and experimental archaeology proposes a processes how beer was produced in the New Kingdom (Samuel 2000: 540, Figure 22.20).

[164] See Report 3.9c. This is an estimate based on the rations of loaves and beer given in the Hammamat texts which varied by rank and profession as analysed by Mueller 1975: 253. The calories associated with beer are included in the cereal calorie requirement of 75.3 million kcals/yr/100000 population discussed above.

[165] A Twelfth Dynasty model of a brewery excavated by J. Garstang in 1903 from a tomb in Beni Hasan on display at the Fitzwilliam Museum in Cambridge (museum reference E.71d.1903).

[166] This includes uplifts for wastage and seed corn (Report 3.21a)

[167] See Reports 3.20a1- 3.20b1. For beer making in Pharaonic Egypt and the longevity of its use from Pre-dynastic times as a beverage see Geller 1992: 16-26 and Samuel 2000: 550-557, 569-570.

[168] French 1999:130.

[169] Source data Megaloudi 2006: 36, Tables 5.3-5.5.

[170] Jones *et al* 1986: 96-103; Jones 1987: 235-238 and Wardle 1987: 313-329.

[171] Gorham and Dering 2003: 249-253.

population. Supporting evidence for the dominance of wheat is provided by the archaeo-botanical evidence from Abu en-Ni'al and el-Hayyat.[172]

Linear B tablet (PyAn128) show that the Mycenaeans valued wheat more than barley and this possibly reflects the fact that barley was easier to grow than wheat. Two units by volume of wheat were exchanged for 3.75 units of barley.[173] A papyrus dated to 256 B.C. (*S.P.*, 1, 39) records that the value of barley was 40% less than wheat.[174] The importance of wheat over barley as a cereal crop is shown in the text Un 1322 from Pylos, where wheat was used to value cloth.[175] On the other hand Theophrastus describes the flexibility of barley as a crop when referring to the fertile soil of Chalkeia in Rhodes. He writes that the soil was capable of a second crop of barley and that the second crop could be harvested at the same time as the slower growing wheat.[176]

Allbaugh's ethnographic study of '*Crete: A Case Study of an Underdeveloped Area*' following the Second World War is particularly useful to this study as it was one of the first truly scientific studies of the economic and social conditions of a rural community that used traditional farming practices.[177] Its thoroughness and breadth has made it a much cited study and it has become a benchmark for its genre not only on the findings but also its methodology.[178] Allbaugh's study of Crete has been used

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[172] Gorham and Dering 2003: 253 citing Fall, Lines and Falconer 1998: 107-125.
[173] Chadwick 1976: 108-110.
[174] Cited by Darby, Ghalioungui and Grivetti 1977: 484.
[175] Killen 1995: 217-219.
[176] Theophrastus *HP* 8.2.9. The vagaries of the climate in the Aegean must have made this an exception rather than the rule.
[177] Ploughs were pulled by oxen, manure was used in preference to fertilizers, and donkeys were the main form of transport (Allbaugh 1953: 249). Only 24% of farmers had steel ploughs with 42% having wooden ploughs (Allbaugh 1953: Table 44). In 1929, 45% of farms had an average size between the range 0.2-2.5 ha and 24% between the range 2.5-5 ha. By 1948 farms with an average size between 0.2-2.5 ha had only risen to 47% of all farms while farms in the range 2.5-5 ha had fallen to 16% of all farms (Allbaugh 1953: 253, Figure 12).
[178] Riley 2002: 64, Gallant 1991: 42, 63-65. Allbaugh's study extends beyond Cretan agriculture, presenting a full sociological study of a rural community; the Cretan diet, mortality rates, housing conditions, schooling, transport, earnings and much more. He also makes comparisons with other rural communities in Italy, Mexico and Egypt that provide a check and balance on his results. The data covering 176 tables were collated by Iowa University (funded by the Rockerfeller Foundation) under Allbaugh's leadership and can be considered as thorough and accurate as any contemporary governmental data. The population of Crete in 1951 was 462,000 and therefore of a convenient size to estimate the diet for the 100,000 population sample used in the model (World2C TM Multimedia 1999 – 2007 citing Cretan national statistics, accessed 10th April 2007, available from http://www.sfakia-crete.com/sfakia-crete/people.html). This is not to say that the population of Crete reached 100,000 in the LBA, but the results will be applicable to dry farming populations in general.

with adjustments to estimate the proportions of crops that made up the diet of Cyprus. Allbaugh's study shows that in 1947/1948 A.D., 50.8% of the calories consumed in Crete were provided by cereals, potatoes, honey, and alcohol, again showing the dominance of carbohydrates in the diet.[179] The evidence is limited but unlike Egypt more emmer wheat was grown than barley. Allbaugh's study results have been adjusted in AGCALC Reports 3.4g to reflect that probably in antiquity less olive oil was used in the diet as a result of a lower scale of production. Olive oil production in antiquity is discussed further in the next section. The resulting proportions of food stuffs required to provide the required total calories of 86,065 million kcals/yr/100000 population are given in Reports 3.9a-3.9b. For this thesis it has been assumed that Cypriot agriculture in antiquity was similar to that found on Crete as the climate, latitude, range of crops grown, and the island topography are comparable.[180] Of this total calorie requirement of 86,065 million kcals/yr/100000 population to feed 100,000 population the proportion of carbohydrates contributed 60.4% (51,983 million kcals/yr/100000 population) of the total calories consumed.[181]

As noted above, hydraulic cultures whose agriculture is reliant on irrigation suffer from build up of salt levels that are detrimental to the growth of wheat. For rain fed Cyprus, without this build up of salt more wheat could be grown than Egypt, so it is assumed that the calorie contribution of barley and wheat are 45 and 55% respectively.

### 3.2.4 Other contributions to the LBA diet

This section estimates the proportions of crops grown that made up the LBA diet. The evidence above shows that cereals played a major part. This staple was supplemented by olive oil, pulses, and limited quantities of protein and dairy products. Allbaugh's ethnographic study of Crete has been used to estimate the proportions of food types that made up the Egyptian and Cypriot diet. The proportions of the diet for Crete are given in the second column of the table below. These percentages have been used to prorate the calorie requirements to support a

[179] Allbaugh 1953. See Report 3.9a for full details of the study.
[180] Solsten 1991.
[181] Report 3.9b.

100,000 sample of the population, 86,065 million kcals required/yr in Section 3.2.2 above.

| Food type | %split by food type of the 1947/48 Cretan diet analysed by Allbaugh | Allbaugh study adjusted assuming lower olive oil content in antiquity | Energy in Million kcals required/yr/ 100000 people |
|---|---|---|---|
| **Cereals** | 46.2 | 59.9 | 51553 |
| **Other carbs.** | 1.7 | 0.5 | 430 |
| **Pulses and veg.** | 11 | 13.1 | 11275 |
| **Wine** | 2.9 | 1.2 | 1033 |
| **Protein** | 7 | 6.4 | 5508 |
| **Dairy** | 2.9 | 1 | 861 |
| **Oils and fats** | 28.3 | 17.9 | 15405 |
| **Total** | **100** | **100** | **86,065** |

**Table 3.5: The percentage mix of food types of the Cretan diet from Allbaugh's Cretan study**

The discussion will now consider the other components of the LBA diet and compare them with Allbaugh's Cretan evidence and adjust accordingly the % split of food types for the Egyptian and Cypriot diets.

## Olive oil use in the Eastern Mediterranean

The overall proportion of cereals in the LBA diet from the dry farming regions was probably lower than in Egypt as their diet was supplemented by vegetable oils, and almost certainly by olive oil. The archaeo-botanical evidence shows olives were indigenous around most of the Mediterranean, demonstrating how easy it was to grow wild olives in the right conditions (Figure 3.18).[182] The ideal conditions for olive trees are on the sea facing slopes of hills between 300m and 1200m, but not in areas where the average monthly temperature falls below 10°C. They can grow on poor soil and are drought resistant, which make them ideal for marginal grazing land above the plains and lower slopes normally dedicated to cereals and pulses.[183] Climate and topographic conditions in Egypt are therefore not conducive for widespread cultivation of olive trees unless they are constantly irrigated.[184] Prior to the LBA, olive oil was probably obtained from wild olives which have smaller fruit and lower oil content than those from domesticated olive trees.[185] Renfrew, Zohary and Hopf suggest that the wild and cultivated olive may even have been different

[182] Zohary 1969: 146, map 1 and Zohary and Hopf 1975: 321.
[183] Aschenbrenner 1972: 53-54.
[184] Serpico 2000: 398 and Hepper 1990, 1992: 104. In modern Egypt they form an important crop around the Siwa Oasis.
[185] Bunimovitz 1996: 49-50 and Stager 1985: 173.

varieties.[186] Renfrew suggests that as the olive grows well in marginal land and on rocky slopes, it was a key determinant in the development of the Cyclades and Minoan cultures. Oil lamps found in both Crete and the Cyclades suggest that olive oil had been exploited there as early as the EBA.[187] Wild and domesticated varieties of the olive have been found in Neolithic and Chalcolithic contexts in Cyprus.[188] The high calorific value of the olive and its oil provides a relatively low labour source of calories to supplement the cereals and pulses. Variations on this basic diet are evidenced from the ration Linear B tablets from Pylos and Knossos where figs were distributed to the workers.[189] Most scholars accept that the diet for the Aegean and Levant in the LBA included olive and wine together with small quantities of meat or fish protein to supplement the staple source of carbohydrates, wheat and barley.[190]

Allbaugh's ethnographic study of the Cretan diet in the 1940-1950's A.D. shows that 28.3% of the calories required were met by olive oil and fats (Report 3.4g).[191] Having nearly a third of the daily calorie requirement supplied from olive oil would have made a significant difference to the area of land under cultivation and the manpower required. To apply this assumption to the LBA requires further evidence and the available evidence is examined in the following section.

### Evidence from the Aegean and Cyprus

It is known from the Knossos Linear B tablets that olive oil was collected from both wild and domesticated sources with a ratio of wild to cultivated varieties of 7:2 respectively.[192] It is not clear if olives were first used for culinary purposes and/or for the production of oil. It is clear that by the LBA both wild and domesticated varieties were used, but the extent to which they were used in the everyday diet is not so clear. Riley, using the results of GC/MS tests (gas chromatography/mass spectrometry),

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[186] Renfrew 1973: 131-132 and Zohary and Hopf 2000: 137-138. Renfrew, J.M. states that the wild form of olive tree was probably the variety *Olea chrysophylla*. Olive stones from this variety have been found in third millennium contexts across the Eastern Mediterranean.
[187] Renfrew 1972: 285-287.
[188] Hadjisavvas 1992: 3.
[189] Palmer 1989: 89-124 analyses the subsistence rations at Pylos and Knossos using information from the PY Ab, PY An 128 and KN Am 819 Linear B tablets.
[190] Coombs, Coppock and Diamond 1947, Foxhall and Forbes 1982: : 41-90, Gallant 1991, Halstead and Barrett 2005, Milano 1989: 201-271, Palmer 2003: 125-138, and Sarpaki 1992: 61-76. This combination has that has become known as the Mediterranean triad.
[191] Allbaugh 1953: 107, Table 9.
[192] Chadwick 1972: 122 and Melena 1983: 97-103.

shows that residues of fatty acids from cold pressed Cretan olive oil and fish oil were key components of the Aegean diet.[193]

**Pithoi in LBA Mainland Greece, Crete, and Cypriot contexts used for storage of olive oil**

The size of the pithoi however found in Mycenaean palaces in Greece and Crete and storage centres in Cyprus indicate that the volume of production of olive oil in the LBA was significant. LC IIC pithoi from the Pithos Hall building X in Kalavasos-Ayios Dhimitrios are a case in point where the total capacity of the pithoi estimated from volumetric studies indicates between 35,000 and 50,000 litres could be stored in the magazines (Figure 3.19).[194] Twenty samples taken from the lower bodies of the Pithoi have been GC/MS tested and the majority have been shown to have held olive oil.[195]

**Evidence from the Ulu Burun wreck**

The 2,500 olive stones found on the Ulu Burun wreck in a Canaanite jar suggest that either olives were part of the crew's rations or a luxury cargo in their own right.[196] If the former, it would indicate that olives and perhaps olive oil were a part of the LBA diet. The latter would indicate that the quality of olives and its oil varied around the Mediterranean as it does today, providing a niche market for the élite. Renfrew points out that the archaeo-botanical evidence for intense cultivation of olive trees is limited until the very end of the LBA.[197]

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[193] Riley 1999: 8-12 (in particular Figures 6 and 7), 46-55 and 88-107. GC/MS tests separate the lipid mixtures into intact acyl lipids, free fatty carboxylic acids, sterols and hydrocarbons. Computer analysis of these characteristic compounds or groups of compounds provides indicator patterns that can be compared and matched with those of modern food items that have gone through similar experimental cooking processes. For food residues generally and the identification of raw organic materials such as olive oil, fats and wax see Martlew, Beck and McGovern 1999: 17-29; Martlew 2004: 121-148, Evershed *et al* 1992: 187-208, Jones 1992: 209-222, and Panogiotaki *et al* 2004: 121-148.

[194] Pilides 1996: 115. Pithoi 1.6m in height could hold 1,182 litres and those 2m in height could hold ca. 2300 litres. For a site report of building X see South 1992: 133-141. For a reconstruction of the Pithos Hall in Building X showing its scale Figure 3.19.

[195] Keswani 1992: 141-145.

[196] Haldane 1993: 353-354 and Pulak 2001: 37.

[197] For a review of the Aegean textual, archaeo-botanical and archaeological evidence see Runnels and Hansen 1986: 299-307, Riley 2002: 63-75 and Melena 1983: 89-123. Lipschitz 1996:1-10 particularly table 10 for and extensive analysis of the dendroarchaeological evidence of olive trees and stones across the Southern Levant. For a review of Roman classical sources see Mattingly 1988b: 33-56.

**Evidence from the Levant**

Archaeo-botanical evidence for the use of olives in the Levant can be found as early as the Chalcolithic period.[198] A number of EBA olive oil production sites have been identified including one at Beth Yerah, Mitham Leviah, and Tel Yarmuth.[199] Levantine storage jars have been found in Egypt from IV to VI dynasty contexts and these are though to have contained imported olive oil.[200]

Possible evidence of large scale olive oil production is provided in LBA Ugarit by the large deposit of amphorae found in a storage depot at Ras Shamra's port of Minet el-Beida. An olive oil press excavated in 1959 at Ras Shamra (tentatively dated to the end of the third millennium B.C. was of sufficient size to be considered as an industrial installation rather than domestic production.[201] Large lever presses have been found in EIA II contexts at Beth-Shemesh, Tel Dan and Tel Batash in Canaan (Figure 3.20).[202]

## Evidence for the use of vegetable oils in New Kingdom Egypt

Serpico and White give an extensive review of potential indigenous vegetable oils available to the Egyptian in the Pharaonic period: caster, balanos, safflower, linseed, moringa, almond, tiger nut.[203] Of these oils, caster, safflower, and linseed oils have unpleasant taste and odour so are less likely to play any significant part the diet.[204]

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[198] Crushed olives have been identified in pestles from Chalcolithic contexts in the Golan Heights (Epstein 1993: 135-138). Crushed olive stones and possible evidence of olive oil production have been found in Chalcolithic contexts from Tell Abu Hamid and Tell esh-Shauna in Jordan (Neef 1990: 298).

[199] Serpico 2000: 400. For an extensive review of the LBA archaeo-botanical and archaeological evidence for the southern Levant see Genz 2003: 61-66.

[200] Schaub 1961: 14.

[201] Milano 1989: 212, 248, footnote 36. The oil press had two slabs 1.95m x 1.25m x 0.18m and 1.7m x 1.3m x 0.11m on top of each other. Channels directed the olive oil to two settlement tanks (each 0.8m x 0.8m x 0.6m) giving a total volume across the two tanks of 0.768 $m^3$. Its function is indicated by crushed olives and a perforated limestone strainer. Assuming average density of olive oil was 860 $kg/m^3$, a planting rate 100 trees/ha, and with the average production of 281 kg/ha the area dedicated to growing olive trees to fill the vats would require 2.4 hectares (see Reports 3.14a-3.14b in AGCALC with full references).

[202] Callot 1987: 204-208; Callot 1994: 191-196. For the Canaanite evidence see Borowski 1987: 122-125, Figures 20-22. Three sites that clearly show the increase in the scale of olive oil production in the Iron Age II are those from Beth-shemesh, Tel Dan and Tel Batash (Kelm and Mazar 1982: 126). At Tel Dan and Tel Batash large weights were found in Iron Age II strata suggesting the use of beam presses to improve extraction rates. Smaller production centres have been found at Tell Beit Mirsim and Bethel (Albright 1943b: 20-21).

[203] Serpico, M. and R. White 2000: 391-405.

[204] Serpico, M. and R. White. 2000: 392,394, 396 and Bedigian 1985: 164-170.

Indian and Egyptian ethnographic evidence shows linseed is used today for frying and is an ingredient in the traditional bean stew *ful medammes* therefore opening the possibility that linseed oil may have had some culinary role in the Pharaonic period.[205] Moringa, almond, and tiger nut oils are edible. Almond oil would have been rare and expensive as it grows with difficulty in the Egyptian climate. All of these oils were probably used for other purposes than culinary applications.[206] It is unlikely that sesame was grown in Egypt in the New Kingdom. Sesame plants grow easily in Egypt today but were unlikely to have been grown until the development of integrated basin-canal irrigation in the Ptolemaic period (Figure 3.21). The annual inundation coincides with the sowing season of sesame in mid June-July, making cultivation almost impossible except possibly on a small scale in the Fayum and the Delta.[207]

Charred archaeo-botanical evidence from Kom Rabʿa at Memphis indicates that the olive had arrived in Egypt by the 13th Dynasty in the Middle Kingdom.[208] Some scholars have argued that the hieroglyph *bꜣḳ* used in Middle Kingdom texts indicates olive oil.[209] While olive stones have been found at Amarna, the lack of more widespread evidence from other New Kingdom sites suggests that the olive and its oil were high status consumables for the élite.[210] The fabric of one of these jars has been examined by Serpico and which matches similar Syrian jars found in Amarna used to transport *nḥḥ* oil, but to date it has not been possible to differentiate between olive oil and sesame oil.[211] The fact that so many containers of vegetable oil have been found at Amarna and at the harbour warehouses at Ras Shamra in Ugarit

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[205] Eckey 1954: 546 and Manniche 1989: 116.

[206] Osborn 1968: 173, Serpico, M. and R. White. 2000: 401 and 402.

[207] Serpico 2000: 398. Seeds have been found in a jar at Deir-el Medina and possibly sesame seeds have been found in the tomb of Tutankhamun, though not conclusively identified to the satisfaction of all scholars (Bruyère 1937: 109). The limited evidence before the Ptolemaic period suggests only limited production if any occurred in the LBA. For a full biography for the Tutankhamun evidence and other sites see Serpico 2000: 397-398.

[208] Murray 2000b: 610, table 24.1. It is not known if they were grown locally or imported.

[209] Serpico 2000: 399 with full references.

[210] Renfrew 1985: 188.

[211] The botanical identity of *nḥḥ* is uncertain as it could be olive oil or sesame oil. A large number of jars labelled *nḥḥ* have been tested using GC/MC techniques the results attest to oil but not to the botanical species (Serpico 2003: 372 and Serpico 2004: 104-105).

indicates that vegetable oil production in the Levant was of sufficient quantity and quality to be exported.[212]

**Summary of the assumptions used in the model for olive oil**

From the archaeo-botanical and textual evidence above it is assumed that olive oil was used in the LBA diets across the population for all cultures of the Eastern Mediterranean with the exception of Egypt. Sesame oil was a part of the Levantine and possibly Mesopotamian diets but not for the general populace of Egypt.[213] As production techniques and distribution would not have been as efficient as olive oil production in Allbaugh's study, it is assumed for dry farming calculations that 17.9% of the diet was fats and olive oil rather than the 28.3% from Allbaugh's study.[214]

For Egypt it has been assumed that only the élite the production of vegetable oils were not used for consumption but were used instead for the base of unguents and perfumes. The manufacturing process to produce oils from indigenous Egyptian plants was laborious and time consuming compared with the fleshy high oil contents of olives.[215] Oils and fats are a key ingredient of a well balanced diet as the lipids carry vitamins and play a part in renewing cells. It has been assumed therefore that at least the Egyptian non-élite received the lipid requirements from rendered fat taken from wildfowl, and occasional zebu and ruminants as discussed in 'protein in the LBA diet' below.

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[212] Gophna and Liphschitz 1996: 147-151.

[213] Serpico 2000: 407-408. Zohary and Hopf 2000: 133 have doubts that sesame oil was consumed in Near Eastern diets in the LBA based on the fact that archaeo-botanic evidence can only be positively identified with certainty for the Levant in the 1st Millennium B.C. (Bedigian 1985: 159 and Postgate 1985: 145-149 takes a different view and suggests that references to Šmaššamū in Middle Assyrian Akkadian texts particularly *VS 19, 9* and *VS 19, 33* indicate that sesame oil may have been produced in Mesopotamia ca. 1400-1000 B.C. His evidence is from the Akkadian texts which describe a production process to extract oil that is similar to that used in Syria in the 19th Century A.D. and in rural India today.

[214] Allbaugh 1953: 126, Table 11. It has been assumed a lower figure for olive oil because yield rates in antiquity were lower in antiquity than traditional Cypriot second half 20th century production ( Sources from antiquity kg/ha and 306 kg/ha respectively discussed below in Section 3.2.6 and Report 3.14a-3.14d). Olive oil presses were smaller in the LBA/EIA period than those used in the time of Allbaugh's study (Figure 3.20). In Cyprus, due to the low rainfall the development of the olive trees with minimal irrigation, if any, was very slow and their yields would have fluctuated year to year. Further work on olive oil yields in antiquity is required. To test the sensitivity of the model one case assumed for Cyprus that no olive oil was included in the diet and the calories substituted with grain. The total agrarian workload increased by 2312 workers (5%) showing that the overall conclusions of the study is not invalidated by the assumptions used for olive oil content in the Cypriot diet.

[215] Serpico, M. and R. White. 2000: 405-407.

## Pulses, vegetables, and fruits

The archaeo-botanic evidence from 30 Egyptian sites and tombs shows that a wide range of pulses, vegetables, and fruits formed part of the Egyptian diet in the Pharaonic period. The arid climate of Egypt has ensured that tomb offerings of ancient fruits and vegetables have survived through desiccation. The most common type of pulse found in tomb offerings was lentils (*Les culinaris*).[216] It has been assumed that 13.1% of the calories required for Cyprus were supplied by pulses, fruit, and vegetables, the same as the Cypriot diet in the Allbaugh study.[217] For Egypt a higher percentage of 16% has been assumed in AGCALC because vegetables, pulses and fruits are easier to grow in Egypt and, as noted above, fewer calories were supplied from vegetable oils.

## Protein in the LBA diet

Meat did not feature significantly in the diet of the non-élite in the LBA. It is true that long before the LBA period, domesticated long and short horned cattle, sheep, goats and pigs were found across the Eastern Mediterranean. However, with the exception of animals bred for sacrifice or for the conspicuous consumption of the élite, there is little evidence that animals were bred primarily for meat production for the common man.[218] The one exception may have been pigs which were husbanded in the Workmens' Village at Amarna.[219] It is more likely that meat from domesticated animals entered the general diet when old age made their prime working function unviable.

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[216] Murray 2000b: 609-655, particularly Tables 24.1, 24.3, and 24.4.

[217] This is based on the assumption that as evidence of vegetables and fruits have been found in the textual and archaeological record across the Eastern Mediterranean then on the basis of reasonableness they would have been grown in Cyprus. Egyptian evidence given in preceding footnote, for LBA Aegean see Sapaki 2000: 61-76, and for Mesopotamian evidence see Wiggermann 2000: 197.

[218] Bulls in particular were bred for religious purposes. At Memphis in Egypt the Apis bull was so revered it was worshiped and mummified. Close to the Aten temples large slaughter houses have been excavated. See Halstead and Barrett 2005 for the role food had in the conspicuous consumption of the élite in Pre-historic Greece.

[219] A pig farm has been excavated with a series of pens attached to a workman's house in building 300. The size of the operation suggests that the pigs were destined for market rather that supplying meat to the farmer or local community. They were fed on grain and their bone assemblages show they were slaughtered between one and two years old (Kemp 1991: 256, Plate 10). Janssen's analysis of Deir el Medina commodity prices shows that a pig was valued in terms of exchange at 3 *deben* of copper and a goat at 2-3 *deben* of copper (Janssen 1975a: 10).

To supplement this irregular supply of meat, additional supplies would have entered the diet through hunting and fishing.[220] Textual evidence from Middle Kingdom Lahun shows that large quantities of fish were consumed. In one papyri list 2,000 fish were caught and in another 1,400, of which 1,000 were gutted.[221] There is some evidence that poor people could purchase meat from temples when a surplus was available, and that the Pharaoh distributed meat (mainly beef) on feast days.[222] With the high prevailing temperatures in the Eastern Mediterranean and the irregular supply of carcasses at a family level, techniques were developed for meat preservation. Egyptian tomb paintings, supplemented with archaeo-zoological evidence, show the drying, salting (dry and wet), smoking and the use of fat, beer, honey as a preservative.[223]

This thesis has assumed that meat played only a small part of the diet for LBA dry farming workers but when it was consumed it comprised predominantly mutton, goat, fish and wildfowl. As sheep and goats were more common outside of Egypt a mutton/goat protein intake is assumed to be on average 20 kg/person/year.[224] In Egypt with fewer sheep and goats the mutton/goat intake is assumed to be 5 kg/person/year.[225] The main source of meat for the non-élite was fish and wildfowl, and texts show that the monthly ration of fish to the tomb workers at Deir el-Medina was 15 kg/month.[226] Large migrations of geese and duck each year meant easily accessible sources of meat for all social classes. It is also known from texts that large

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[220] Brewer and Friedman 1989: 11 have identified 23 species of fish from Old Kingdom tomb scenes alone, all of which could have entered the Egyptian diet. The fish supplied to the workman at Deir el-Medina as rations were tilapia, synodontis, mormyrus, and possibly alentes (Brewer and Friedman 1989: 16). Fish bones identified from LBA contexts at recent excavations in Troy have identified 61 fish remains; of these 21 were from the tuna family, 8 were mullet, 14 sea bream and 18 other assorted types (van Neer and Uerpmann 1998: 246, Table 1).

[221] Szpakowska 2008: 97 citing papyri UC32097B and UC32142B in Collier and Quirke 2006: 152-153, 172-173. These two examples are part of a large number of accounting lists of catches and numbers of fish gutted.

[222] Ikram 2000: 669 citing Peet 1934: 185-199 and commenting on Papyrus Bulaq II.

[223] Ikram 2000: 659-669 for methods of preservation. For a full analysis of Egyptian meat processing from slaughter to consumption see Ikram 1995.

[224] Redding 1993: 85-89, Figure 4 analysis of bone assemblages shows that the ratio of sheep to goats was 2:1 for Mesopotamia and Anatolia in the LBA. The ratio of sheep/goats to cattle as 11:1 for intensive farming and 30:1 for less intensive farming.

[225] The Nile valley of Egypt with its annual inundation favours arable farming leaving only limited marginal land suitable for rough pasture with low stocking rates.

[226] Janssen 1976: 18. Janssen's monthly fish intake equates to 15 kg/person/yr assuming this has to be shared between an average family size of 6 individuals (Report 3.4f in AGCALC). For size of family see Report 3.21 in AGCALC.

flocks of geese were bred for meat.[227] The diet in the model for Egypt therefore reflects the abundance of fish and wildfowl and the average protein intake is assumed to be 30 kg/person/yr. The intake for other regions of the Eastern Mediterranean is assumed to be 40 kg/person/yr which reflect the increased use of mutton and goat as their prime source of protein.[228] Report 3.4b quantifies the number of sheep required to provide 100,000 people with mutton/goat meat. At a rate of 20 kg/person/yr this amounts to the culling of 98,033 animals, which equates to 6 to 7 animals per family on average.[229] This seems reasonable for regions such as the Aegean where large flocks are known to have existed in the LBA.[230] For Egypt this possibly reached the upper limit of the number of sheep that could be culled while still retaining viable breeding flocks. In this event, other sources of protein may have had to been found e.g. fish or wild fowl from the Nile.

## Dairy products in the LBA diet

Cheese formed part of the Egyptian diet. An unknown type of cheese formed part of a funerary meal which was found in an élite tomb (tomb 3477) at Saqqara.[231] A sunken relief on the Eleventh Dynasty sarcophagus of Queen Kawit from the temple of Mentuhotep II in Deir el-Bahri, West Thebes shows a cow that sheds a tear as she loses the milk which could have fed the calf tied to her leg (Figure 3.22).[232]

Allbaugh's study shows that 1.4% of the annual total energy requirement was provided by milk and cheese. Using these assumptions Report 3.4c in AGCALC shows that the requirement for Cyprus would be 9 kg/yr.[233]

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[227] Ramesses III gave 2,940 live geese, 5,200 live turpu geese, 20 fat geese, and 126,300 live waterfowl as a gift to Amun (Breasted 1906: 133, Vol. 2, text 235).
[228] The contribution of mutton/goat, fish and fowl taken for the Egyptian diet are assumed to be 5, 15, and 10 kg/person/yr respectively (Report 3.4e in AGCALC). Those for areas outside of Egypt are 20, 15, and 5 kg/person/yr respectively (Report 3.4d in AGCALC).
[229] The analysis uses the following two assumptions. The average sheep had 18 kg of useable off-the-bone meat (Lyman 1979: 542, table 4) and the calorific value for mutton is 2,500 kcals/kg. This value is normally applied to lean meat and may seem to be in error as mutton has a high fat content. The reason for using it is that in antiquity fat was a useful commodity and would have been cut off for other uses such as cooking, lighting or as a base for perfumed unguents (Manniche 1999: 83, 85 and Serpico 2000: 407-408). Any remaining attached fat would melt into the fire during roasting.
[230] See Halstead 1990-1991: 343-365 and Killen 1964: 13-15 for discussion on the large size of Aegean LBA flocks.
[231] Zaki 1942: 295-313.
[232] Brewer, Redford and Redford 1994: 85.
[233] The model assumes that children under 3 are breastfed. This model will use the same percentage as Allbaugh, as this amount can be easily met from the 98,033 sheep quantified above when analysing

## Contribution of wine, and beer to the LBA diets

The wild grape is found around the Mediterranean basin with the exception of Egypt and Libya (Figure 3.23). Exploitation of wild grapes started in mainland Greece ca. 6000 B.C. The archaeo-botanical evidence indicates that grapes have been grown in the Aegean from at least 3100 B.C. Winemaking itself is attested from the remains of pressed empty grape skins together with grape pips and stalks in pithoi in Early Minoan contexts at Myrtos and Early Helladic contexts at Aghios Kosmas.[234] Minoan Linear A and Mycenaean B administration records show that vines were grown in conjunction with figs. Linear B yield assessment, distribution and collection records show that wine was not produced in the palaces, but by the farmers who delivered fermented grape juice to the palace in return for rations. Tablets PY Gn 720 and PY Gn 428 show that large quantities of wine were produced. Linear B records suggest that ordinary workers received wine at religious festivals but there are no records to suggest wine was a part of the day-to-day diet.[235] Wine was produced for at least the élite in the LBA Cyprus, but again it is uncertain if it entered the diet of the non-élite.[236]

The model assumes that wine formed 1.2 % of the diet of the élite and the equivalent calories for the workers were supplied by figs or dates.[237] Textual and artistic evidence in the Near East and Egypt shows that there were local markets. It seems

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protein requirements. One kg of dairy solids can be made using traditional methods from 6 kg of sheep's milk or 12 kg of goat's milk. Ewes lactate on average for 150 days and lambs are weaned on average after 50 days with each ewe producing 0.4 kg/ day (Stol 1993: 101). The resulting surplus of 100 days of milk production has the potential therefore of supplying 1,960,660 kg/yr of dairy products which more than covers the dairy demand of 9 kg/yr. Ethnographic studies of milk from sheep, goats and cattle give calorific values of 698 (4 studies), 1,114 (3 studies), and 668 kcals/kg (4 studies) respectively (Dahl and Hjort 1976: 153-156, 215-217, particularly table 9.3 for sheep and goat data). Full bibliographic references of the ethnographic studies are included. The average of all eleven studies is 814 kcals/kg and has been used for this study.

[234] Renfrew 1995: 263, Mylonas 1959: 39 and Zettler and Miller 1995: 126. Crushing the grape skins releases the natural yeast *Sacchararomyces ellipsoideus* in the "bloom" to enable fermentation to start.

[235] Palmer 1995: 277-278.

[236] Steel 2002a, Steel 2004a: 161-180, and Steel 2007 forthcoming.

[237] As evidence is lacking for the quantity of wine consumed in the LBA but it is known the fruit was available in all parts of the Eastern Mediterranean Allbaugh's estimate has been used. See Palmer 1989: 89-121 for rations of figs supplied to Mycenaean workers. For this analysis 20 kg/worker/year has been assumed.

logical that local markets would have existed in the LBA giving the common people the opportunity to gain some degree of variety to their diet.[238]

Organic residues have been found showing that beer or beer/wine mixture were produced in the LBA Aegean. The fabrics of two pithoi (ca. 2200 B.C.) from Myrtos have residues which indicate that barley or a barley product had been added to wine.[239] The organic residue tests on tripod cooking pots from the Middle Minoan site of Apodoulou in South-West Crete indicate that beer was also brewed. Pots from Late Minoan IA and IIIA2 indicate that a cocktail of resinated wine, beer, and honey mead was produced.[240] The bulk of the evidence indicates that wine was the drink of choice and therefore beer production will be excluded from this analysis for Cyprus.

The archaeological record shows that the royalty and the élite of Egypt consumed wine but it is unlikely that wine played a significant part in the general diet of LBA Egypt.[241] Wine has been considered to be mainly red in ancient Egypt linked with the blood of Osiris, the God of resurrection. No texts have been found that refer to white wines from Pharaonic Period (3150–332 BC). The first known white wine known from Egypt was made near Alexandria during the third century A.D. LC/MS/MS testing of wine amphorae in Tutankhamun's tomb show that some contained white wine presumably imported.[242] To the Egyptians, wine was closely associated with religious activities. It was thought to have divine qualities and was given as a temple cult offering to the god. The most common image shown in temple scenes, tombs

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[238] Unfortunately Linear A and B tablets are administration tablets and do not record day to day life records of local markets. It is clear from Near Eastern records and particularly from Deir el-Medina that local markets flourished enabling short term surpluses to be exchanged for a whole range of goods and services (McDowell 1999: 73-78, 84-85, Kemp 2002: 303-304, 324-326, Figure 114 and Haring 2003: 249-272).

[239] Martlew 1999: 159.

[240] Martlew 1999:162,166, 172 and Martlew 2004: 140-142 with full references.

[241] In particular wine jars, seals, labels and presses. For a full description and biography of archaeological evidence and the scientific analysis of evaporated wine residues see Murray, Boulton and Heron 2000c: 579-599.

[242] Guasch-Jané *et al* 2006: 1075-1080. Detection by mass spectrometry (MS) permits the analysis of compounds that cannot be detected with traditional visible, ultraviolet, fluorescent, or electrochemical detection methods. Following liquid chromatography (LC) purification, the sample is vaporized, ionized, and further separated by the mass spectrometer according to the mass-to-charge ratio of the ions created. This process results in improved sensitivity and specificity over traditional LC methods. For analytes requiring further separation, tandem MS (MS/MS) can be applied. The MS/MS system relies on collecting selected parent ions from the first MS, fragmenting them into product ions, and separating again by mass-to-charge ratio. Thus, MS/MS includes an additional separation step beyond the initial LC/MS (Nichols Institute 2008. Accessed 19th Sept. 2008. available from http://www.nicholsinstitute.com/Endocrinology/Documents/LC_MS_MS%20TM.pdf ).

and stelae is the sprinkling or pouring of wine on offering tables or the ground or other objects and persons as a purification ritual.[243] Wine and beer were also offered in funerary cult offerings to the *ka* of the deceased. Wine called *nfr* was offered to the gods of Egypt by the temple priests at the great festivals which were dictated by the temple calendar. The gods took the spiritual essence from the wine which by reversion was available for consumption by the priests.[244]

Considerable investment was made in temple viticulture in the New Kingdom; the Ramesseum alone owning 18 vineyards in Lower Egypt and the Delta.[245] Ramesside labels on wine amphorae show that at least 36 estates produced wine, mostly located in the north-eastern Delta which the Ancient Egyptians called Kaenkeme.[246] Tomb paintings and textual sources show that wine was consumed outside on occasions not associated with temple ritual and was sometimes taken to excess (Figure 3.24).[247] The importance of wine for the élite is indicated by twenty-nine tombs and one temple from the Old Kingdom, eight tombs from the Middle Kingdom and forty-two tombs from the New Kingdom which have paintings showing the wine making production process.[248] The process was a time consuming one that incorporated twelve stages from harvesting through to consumption (Figure 3.27).[249]

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[243] Dils 1993: 111ff.

[244] Kitchen 1992: 115.

[245] Kitchen 1992: 116-120, Figure 1 and table 1A.

[246] McGovern 2003: 143 and Lesko 1995: 226-227. Wine was also produced in the Nile Valley itself mostly on the west bank probably maximising the hours of sunlight. In the Ramesseum, wine labels show wine was produced from estates on the west bank opposite Thebes. At Amarna, 165 wine labels indicate wine was produced in quantity from the "Western River" estates owned by the royal family (Lesko 1995: 226).

[247] Darby, Ghalioungui and Grivetti 1977: 579-587 gives a full account of textual evidence for excessive drinking in Ancient Egypt and homilies for temperance and control. Tomb paintings also portray excessive drinking: a lady vomiting at a banquet and two intoxicated men carried away from a banquet (Darby, Ghalioungui and Grivetti 1977: 585, Figure 14.14 after Brussels Museum, No E. 2877 and Murray, Boulton and Heron 2000c: 578, Figure 23.3 adapted from a drawing of a scene from the tomb of Senna TT169 originally published in Wilkinson 1878: 168, Figure 148.

[248] Lerstrup 1992: 61.

[249] The twelve stages are tending the vine, picking grapes, transporting the grapes, the pressing vat, beating the working rhythm, the sack press, filling jars, sealing jars, registration, fermentation, transportation of wine-jars and offering to the harvest god Renenutet (Lerstrup 1992: 64-76, Figures 8-17). No single tomb has the full range of twelve stages but combinations of them are depicted to represent the process. One of the most complete portrayal of wine production is seen in the Tomb of Intef in the reign of Tuthmosis III.

## Summary of the LBA Diet

Any analysis of the LBA diet can never be definitive, but this section has incorporated as wide a sample of evidence to make the assumptions as representative as possible. The evidence for the dry farming regions has come primarily from ethnographic evidence from the Aegean. Where applicable, this has been supplemented with Linear A and B texts and archaeo-botanical evidence. Our understanding of the diet in New Kingdom Egypt is greater than that of the dry farming regions because so many papyri and tomb paintings have survived in the archaeological record. Careful consideration has been given to archaeo-botanical and archaeo-zoological evidence because most textual and artistic Egyptian evidence reflects the world of the élite and not the general population. Combining all types of evidence gives a check and balance that provides the best possible information on the LBA diet. The diet is summarised in the table below and provides the input assumptions to estimate the weight of crops required to feed the demographic population sample of 100,000 people.

| Region | Cyprus | | Egypt | |
|---|---|---|---|---|
| Food type | % | Million kcal /yr | % | Million kcal /yr |
| Barley | 27.2 | 23,392 | 56.5 | 48,605 |
| Emmer wheat | 33.2 | 28,591 | 18.8 | 16,202 |
| Pulses and veg. | 13.1 | 11,275 | 16 | 13,770 |
| Wine/grape juice | 1.2 | 1,033 | 0.3 | 258 |
| Meat protein | 6.4 | 5,508 | 4.3 | 3,701 |
| Dairy products | 1 | 861 | 0.5 | 430 |
| Oils and fats | 18 | 15,405 | 3.6 | 3,099 |
| **Total** | **100** | **86,065** | **100** | **86,065** |

**Table 3.6: Summary of the assumptions used in modelling the LBA Diet**

# 3.2.5 Weight of crops required

In Section 3.2.2 the demographic study showed that 86,065 million kcals/yr were required from the LBA harvest to feed 100,000 people if they were to remain healthy. The weight of crops needed to provide the 86,065 million kcals/yr is calculated by the formula, calories for each food type (kcals) ÷ calorific value of each component of the diet (kcals/kg).[250] The collated weights of the crops required to be grown are summarised in the table below.[251]

| Weight of crops required to feed 100,000 people/year | | |
|---|---|---|
| Crop | Cypriot kg | Egypt kg |
| Barley | 7,045,783 | 14,640,060 |
| Emmer wheat | 8,611,747 | 4,879,819 |
| Pulses and veg. | 11,218,905 | 13,702,488 |
| Oils and fats | 1,797,340 | 441,150 |
| Wine/grape juice | 1,389,785 | 346,774 |
| Meat protein | 3,396,800 | 2,547,600 |
| Dairy products | 794,070 | 352,920 |
| **Total** | **34,254,430** | **36,910,811** |

**Table 3.7: Weight of crops consumed by 100,000 people per annum**

## 3.2.6 The yield of crops grown in the LBA.

The yield rates are the weight of crops that can be grown on each hectare of ground expressed as kg/hectare for each crop.[252] There are many factors that influence yield rates: short term variation in climate, the irrigation technology, seeding rates, sowing by broadcast or drilling, the size of plot, quality of land, manpower available, tilling methods, weed and pest control, and the genus of cereal grown. This section will evaluate the textual and ethnographic evidence to estimate the yields of crops that are representative of the LBA. An estimate of ancient yields is required because the area of land required in hectares to grow the quantity of food tabulated in Table 3.10 in Section 3.3 below is calculated by dividing the weight of food for each food type (kg) by the average yield for each crop (kg/hectare).

The textual evidence for yield rates in Egypt reflects the randomness of the survival of textual sources. This evidence must be treated with caution as it lacks the contextual information about what could influence the yield rate. This is why this section has predominantly used ethnographic evidence from traditional farming

[250] The calorific value of each component of the diet is given in Report 3.3 in AGCALC.
[251] The results are calculated in Reports 3.4-3.5 and 3.20-3.21 in AGCALC.
[252] This section will use the convention of quoting the units of measurement as given in the primary and secondary sources and its modern metric equivalent in brackets. The following conversion rates have been used for the Egyptian units of capacity and area. In the Old and Middle Kingdoms one sack equated to one khar = 48 litres. In the New Kingdom this changed with one sack equating to one khar but now with a capacity = 76.8 litres. This capacity would weigh approximately 47 or 59 kg for barley and wheat respectively depending on moisture content. The Egyptian unit of area was the aroura with its modern equivalent of 0.2735 hectares. The modern Egyptian unit of area is the feddan 0.42 hectares. For the full conversion rates used in AGCALC see worksheet CONVERSIONS

practices. However textual references do provide a check and balance on the ethnographic evidence.

In Egypt there were three categories of land depending on their proximity to the river Nile and their fertility which resulted from the Nile silt deposited by the inundation. The most fertile land was called *nḫb*-land, average land was *ḳ3yt* land and the poorest marginal land was named *tni*-land.[253] The Middle Kingdom 'Hekanakhte papers' (Ca. 2020-1991 B.C.) uses the word *3ḥt* for ploughed or tilled land and *jwḥ* for land subject to the inundation.[254] Basin land formed by trapping water in the inundation was called *sp3t*.[255] The yield of barley from two plots of *ḳ3yt* land belonging to Hekanakhte, a Middle Kingdom estate owner, produced between net yields of 5-10 khar/aroura. The gross yield rate would be a 15 khar/aroura reflecting the standard share-leasing rent amounted to one third of the crop in the Middle Kingdom.[256] However in the New Kingdom the khar volume changed from 48 litres to 76.8 litres. Hekanakhte's yield of 15 khar/aroura would therefore be equivalent to 9.4 khar/aroura in New Kingdom measurements.[257] Using a conversion rate of 107 kg/ha equals 1 khar/aroura, the yield rate of 9.4 khar/aroura is equivalent to 1,006 kg/ha.[258] A letter from the reign of Ramesses XI shows a grain yield on average land of 10 khar/aroura (1,070 kg/ha).[259] Baer suggests a seed rate to yield rate (hereafter a seed to yield ratio) of 1:10 gives the best fit in his analysis of the Hekanakhte papers.[260] The Twentieth Dynasty Wilbour Papyrus (1152 B.C.) indicates that five sacks of cereal (535 kg/ha) could be grown per aroura on marginal upland away from the river.[261] A small number of farms closer to the river on *nḫb*-land could produce 10 sacks per aroura (1070 kg/ha if the cereal was barley and 1350 kg/ha if the cereal

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[253] Gardiner 1948: 29; 198.
[254] Allen 2002: 149.
[255] Allen 2002: 150. The use of basin irrigation is discussed further in Section 3.4.5 below.
[256] Allen 2002: 160.
[257] Allen 2002: 176. Interpreting ancient texts is difficult as it is not clear whether the return is or is not net or gross of rental fees. Parkinson 1991: 104 interprets the yield as 9 sacks per aroura with presumably 1 sack (10% of gross yield) as tax or rent. If the difference is interpreted as rent, this appears a low rate compared with later sharecropping leases of one third of the crop (Allen 2002: 157).
[258] This assumes a dry density of barley equals 609 $kg/m^3$ and one aroura equals 0.278 ha. If the grain was wheat with a dry density of 769 $kg/m^3$ one kg/aroura would be 135 kg/ha.
[259] Wente 1990: 130-130. A strip of land near Edfu produced 40 khar from 4 aroura giving a rate of 10 khar/aroura. This assumes that one sack of grain was equal to one khar.
[260] Baer 1963: 14-15. Hekanakhte seed rate was 1.5 khar.
[261] Gardiner 1948: 198 and Gardiner 1941: 64-66.

was wheat).[262] An analysis of the Wilbour papyrus shows that a harvest of 5 sacks per aroura would require an area under cultivation for *ḳ3yt* land (best land) of 40 aroura (11 hectares) for every adult and 20 aroura (5.5 hectares) for every youth. Converting this to modern units would indicate expected yields of 853 kg/ha and 1075 kg/ha for barley and wheat respectively.

**Ethnographic evidence using traditional farming methods**

The full data sets (including references) of cereal, pulses and olive oil yield rates based on ethnographic evidence of traditional farming practices in the Eastern Mediterranean can be found in Reports 3.9-3.14 and 3.16a.[263] The yield is also dependent on the quality of the land. The assumptions and statistical analysis of the ethnographic analysis to determine the yield rates of marginal, average, and best land is covered in Reports 3.40-3.41. The averages of this ethnographic yield data determined for crops grown in the dry farming regions and Egypt are summarised the tables below.

| Dry rain fed regions | Yield kg/ha marginal land | Yield kg/ha average land | Yield kg/ha best land |
|---|---|---|---|
| Barley | 408 | 660 | 1,073 |
| Wheat | 399 | 714 | 1,455 |
| Tot. pulses | 455 | 563 | 802 |
| Olive Oil | 181 | 272 | 398 |

**Table 3.8: Average yields based on ethnographic data for dry farming regions of the Eastern Mediterranean**

| Crop | Yield kg/ha marginal land | Yield kg/ha average land | Yield kg/ha best land |
|---|---|---|---|
| Barley | 510 | 825 | 1,342 |
| Wheat | 499 | 893 | 1,819 |
| Tot. pulses | 546 | 676 | 963 |
| Olive Oil | 209 | 313 | 458 |

**Table 3.9: Ethnographic average crop yield rates kg/hectare for Egypt**

The ethnographic data for Egypt (Report 3.12 in AGCALC) refer to a period when fertilisers had been introduced and this has boosted crop yields. When farming practices relied solely on the Nile silt and manure from animals, crop yields would have been less. In 1908 A.D. the recommended fertilizing rate was 75-150 kg/feddan

[262] Gardiner 1948: 29; 198.

[263] The model has the option of combining the Aegean, Balkans, Northern Syria and the Levant cereal and pulses yield data together to increase the sample size. Unless otherwise stated the default condition for the model uses the data with the highest and lowest outliers removed (see Report 3.13c). Note data from Mesopotamia have been included in the Egyptian data as both areas are representative of river dependent irrigated agriculture (see Report 3.12).

of sulphate of ammonia for those areas that were not flooded in the inundation.[264] The yield data has been adjusted downwards to the pre-fertilisation farming conditions using a study of fertilising practices in Egypt for 1920-1939 A.D. which estimates the increase in yield due to the application of fertilizers.[265] This study of fertilising practices showed that, in order to reflect pre-fertilizer farming practices, the yields of barley and wheat should be reduced by 36% and 33% respectively (Report 3.11c in AGCALC has incorporated these factors in Table 3.9 above).

[264] Foaden and Fletcher 1908: 292-293.
[265] Richards 1982: 129-131, table 4.9 citing Nassif, E. 1942. L'Egypte, est-elle surpeuplée? *L'Egypte Contemporaine* 33: 376.

# 3.3 Area of land required to feed 100,000

This section estimates the area of cultivatable land that would be needed to support 100,000 people for a year. The area under cultivation = weight of crop (kg) ÷ harvest yield (kg/hectare). The area calculations are shown in Reports 3.20-3.21 for the Aegean and Egypt. The area required for cultivation is greater than that required for the production of food for human consumption alone and has to be raised for the following reasons:

1. The requirement to produce seed corn for next year's harvest.
2. Wastage incurred through the agricultural and processing cycles.

The fodder requirements for oxen would have been too great for small nuclear family farms and land preparation would probably have been restricted to hoeing. Large numbers of hoes have survived in the archaeological record and many workers are portrayed in Egyptian wall paintings using this method of preparing the land for sowing (Figures 3.25-3.26). The model will calculate two extreme cases:

1. All soil preparation was carried out by yoked oxen pulling ploughs.
2. All soil preparation was carried out using hoes

Combinations of these two extreme cases will be used in Section 3.4 to calculate the manpower for different proportions of the cultivated land under large estates and those in the control of small nuclear farms.

## 3.3.1 Area of land growing cereals and pulses

This section refers only to arable land under cultivation for cereal and pulses and not vegetables. Vegetables are assumed to have been grown as second crops on land close to sources of water and do not require significant additional land. In Cyprus and the Aegean today, also assumed in the LBA, cereals are sometimes grown in olive groves. The model incorporates this extra area of cereal cultivation by including it within the marginal land category.

The results for arable cultivation of cereals and pulses and wastage plud seed corn are shown in the table below.

| Crop | Cyprus area ha | Egypt area ha |
|---|---|---|
| Barley | 12,573 | 15,459 |
| Emmer wheat | 14,780 | 4,509 |
| Pulses | 20,987 | 9,411 |
| **Total** | **48,340** | **29,379** |

| Crop + seed corn + wastage | Cyprus area ha | Egypt area ha |
|---|---|---|
| Barley | 15,905 | 19,854 |
| Emmer wheat | 18,697 | 5,790 |
| Pulses | 26,549 | 12,087 |
| **Total** | **61,151** | **37,731** |

**Table 3.10: Area for cereal and pulses required to feed 100,000 people (top). Area for cereal and pulses required to feed 100,000 people plus the area required for seed corn and wastage (bottom)**

Each year seeds were reserved for planting next year's harvest. The sowing rates used by farmers in antiquity varied considerably and depended on many factors such as soil types and precipitation levels. Theophrastus clearly understood these as he advised that heavy clay soils should have a high sowing rate but sandy soils should have a low sowing rate.[266] He was equally conversant with the influence of climate on the early growth of plants.[267]

In ancient Egypt sowing and yield rates are seldom explicit and have to be interpreted from incomplete data. In particular, the environmental context is rarely stated. Another source of confusion is caused by the widespread practice in antiquity of sowing mixed wheat and barley together and wheat, barley and pulses together, as an insurance against a crop failure.[268]

## Ratio of seed corn to yield

### Textual evidence and ethnographic evidence

Although any statistical approximation of the seed corn to yield would be meaningless for the reasons given above, some indicators are helpful when making assumptions for the model. In most Roman classical texts the seed to yield ratios that have survived are in the range 1:4 to 1:6.[269] Garnsey uses these texts as an input to

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[266] Theophrastus *Historia Plantarum* 8.6.2.
[267] Theophrastus *Historia Plantarum* 8.7.6.
[268] Murray 2000a: 519 and Foaden and Fletcher 1910: 326, 431.
[269] The most quoted being Columella *de r.r.* 2.9.1 ; 2.12.1 of 4-5 modii per iugerem equating to a maximum seed to yield ratio of ca. 1:4 and a maximum gross yield of 500 kg/ha. Sallares points out this may be a misinterpretation of Columella's records as seed to yield ratios and yield rates as

his analysis of agricultural practices in Classical Greece. Using these with Greek texts, Garnsey concludes the seed/yield ratios for wheat and barley for Classical Greece were in the order of 1:4.8 and 1:5.9 respectively.[270] In 1901 shortly before the introduction of chemical fertilisers in Greece, the seed to yield ratio for mainland Greece was 1:4.8.[271]

Evidence of sowing rates for the Pharaonic period through to the Roman period indicate higher ratios of the order 1:10 to 1:12.5.[272] Ramesside Papyri Louvre 3171 giving an account of the Harvest of Amenmose shows that the seed/yield ratio was 1:10.[273] In the Roman period, the seed to yield rate for wheat was 1: 11.5 for the Third Century A.D. estates at Appianus, Euhemeria and Theadelphia. The seed rate was on average 1 artaba/aroura (86 kg/ha for barley and 109 kg/ha for wheat) with an average yield of 11.5 artaba/aroura (992 for barley and 1,254 kg/ha for wheat) and this seed to yield ratio of 1:11.5 was typical of Egypt for this period. Another attested seed rate of 1 artaba/aroura for barley gave a yield of 10.2 artaba/aroura (877 kg/ha). This gives a seed to yield ratio of 1:10.2.[274]

Ethnographic evidence for the Negeb and Aşvan in Turkey where traditional agricultural practices were used suggests seed/yield ratios for both wheat and barley in the range 1:4 to 1:10. The sowing rates in Egypt in the late nineteenth century A.D. were 134 kg/ha for wheat and 81 kg/ha for barley. The corresponding yield rates were 1,828 kg/ha for wheat and 2,089 kg/ha for barley.[275] The seed to yield ratios are therefore 1:13.6 for wheat and 1:26 for barley. These ratios are inflated compared with antiquity as fertilisers had started to be introduced and when reduced

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recorded in the classical period probably relate to ratios of seed sown to seed harvested and not unit areas Sallares 1991: 374.

[270] Garnsey 1992: 148-149 using the evidence of Varro *r.r.* 1.44.1, Columella *de r.r.* 2.9.1 and Pliny *NH* 18.198.

[271] Sallares 1991: 497, footnote 239 citing Tsouderos E.J. 1919. In *Le relèvement économique de la Grèce*. 132. Paris.

[272] For Middle Kingdom sowing rate evidence see Hekanakhte Papers I, 6-7; I, 9-10; I, 12-13; II, *vs* 1-2 'An Eleventh Dynasty farmer's letters to his family' analysed by Baer 1963: 14-15 and James and Gunn 1962: 115.

[273] Gardiner 1941: 57-58 and Baer 1962: 30-31.

[274] See Rathbone 1991: 242-243, 464 for analysis and papyri references .

[275] Willcocks 1889: 255-256. Ross 1889: xix introduction to Willcocks' book give similar ranges. The sowing rates for wheat and barley of 187 kg/ha and 79-89 kg/ha for ploughed land gave yields for wheat (Triticum sativum) of 1835 kg/ha and barley (Hordeum vulgare) of 2303 kg/ha. This results in seed to yield ratios of 1:13.7 and 1: 26. The sowing rates for basin lands in 1910 were 7-8 kela/feddan (211-242 kg/ha) for wheat and 7-9 kela/feddan (167-215 kg/ha) for barley (Baer 1962: 30 citing Egypt, *Almanac for 1910*: 126-127.)

by the factors discussed in Section 3.2.6 are much closer to the Pharaonic textual evidence.

### Assumptions made in the AGCALC model

There is evidence that wheat seeds were less fertile in antiquity than modern wheat varieties and so required more seed for the same unit area.[276] This problem was exacerbated by tetraploid wheat varieties, such as emmer which had lower tillering characteristics.[277] These two factors would result in a lower yield per plant compared with their more modern counterparts. There is an inevitably high level of uncertainty in determining what seed to yield ratios existed in the LBA. The seed to yield ratios of 1:10 (10%) have been used in AGCALC both for dry farming regions and Egypt.[278] Using these ratios for dry farming regions and Egypt in the model show that the area required for seed corn is given in the table below.

| Crop | Egypt | Cyprus |
|---|---|---|
| Land required for barley seed corn ha | 1,805 | 1,446 |
| Land required for wheat seed corn ha | 526 | 1,700 |
| Weight of barley seed kg | 1,907,885 | 954,360 |
| Weight of wheat seed kg | 608,056 | 1,213,800 |

**Table 3.11: Area (hectares) required to produce sufficient seed for next year's harvest to support 100,000 people, for a seed to yield ratio for Cyprus and Egypt of 1:10**

## 3.3.2 Area of land required to replace wastage

Wastage of grain with LBA technology was inevitable.[279] One of the difficulties faced by farmers in antiquity was that the stand heights of the tillers of the same cereal plant varied considerably compared with modern counterparts. Experimental archaeology results of the stand heights of barley and spelt wheat are shown in Figure 3.28.[280] This creates considerable problems when reaping with sickles as the smaller stands are below the average weed level. The higher stands of emmer wheat also created problems as they tended to neck with the head drooping towards the

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[276] Sallares 1991: 374-379.

[277] Tillers are side shoots that arise from buds in the axils of plants which capture more light energy for the plant during growth. Each tiller then goes on to flower which increases the yield. In modern wheat plants 50-70% of grain is produced by tillers, the rest by the main stem (see Thiry *et al* 2002).

[278] The higher ratios in the Roman textual sources reflect the improved Roman irrigation technology of Roman agriculture and have therefore been excluded from the AGCALC analysis.

[279] In the model these are entered as percentage of the total and can be varied by changing the variables in Reports 3.15b and 3.15c for Egypt and Cyprus respectively.

[280] Reynolds 1992: 383-388. These results for the three crops are for one year only (year unspecified) but it was stated that the measurements were taken in the same year and all three varieties grown in the same way and under the same conditions. The seeds had been planted in rows and measurements taken every 0.3 m along the rows. The number of sicco wheat measurements used as a comparator is lower than emmer and spelt as a smaller area had been planted.

ground resulting in losses of grain from vermin. The seed heads of the exposed higher stands were also prone to damage from wind and sun, becoming brittle and breaking off resulting in rot and loss to vermin.[281]

Modern ethnographic evidence presented at the United Nations Symposium on post-harvest Conservation held at Rio de Janeiro in 1978 stated that in the Third World 5% of grain was lost with shattering of grain in the field at harvest time. A further 12% is lost in the threshing process when some grain is left in the ears of corn. Indian ethnographic evidence demonstrates that on average losses due to insects, rodents, and birds amount to 9.3%.[282] Bulk storage of commodities in centralized granaries provides ideal conditions for the rapid proliferation of a range of pests, which can lead to total destruction of the foodstuff.[283] An analysis of lentils in the collection of the Department of Egyptian Antiquities at the British Museum (EA 35990), carbon dated to the early Ptolemaic period showed evidence of infestation by *Bruchidae* (bean weevils). The infestation by the weevils could only have taken place either just before or very soon after the lentils were harvested as this insect only attacks fresh pulses.[284] A recent entomological study from LBA strata R at Beth-Shean in Israel found a Lesser Grain Borer insect (*Rhyzopertha dominica*) which can survive in the high summer temperatures eating grain with very low moisture content. This is significant because it has only been found only twice before at Santorini in a 1628 B.C. context and in the Tomb of Tutankhamun. If more of these insects are found then it may point to a major problem for grain storage in granaries in the Levant and Egypt as the indigenous variety *Sitophilus granarius* is less suited to high ambient temperatures and low humidity.[285] In summary, the losses in harvesting and storage would be relatively high in antiquity. For the model it is assumed that on average 15% was wasted throughout the process from harvesting to threshing requiring 15% more land under cultivation.[286]

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[281] The loss was minimised by gleaning as shown in the harvest scene in the Egyptian Tomb of Nakht (TT52) and the Tomb of Paheri. Hodel-Hoenes 2000: 31, Figure 9 and Tylor 1895: Plate IV. Women and children are seen following the reapers picking up fallen ears of corn. Kemp and Vogelsang-Eastwood 2001: 193, Figure 6.24.

[282] FAO 2007.

[283] Panagiotakopulu 2001: 1238-1242 and Levinson, H. and A. Levinson. 1994: 47-59.

[284] Burleigh and Southgate 1975: 391-392.

[285] Simchoni, Kislev and Melamed 2007: 712-713.

[286] This may be on the low side, as the experience at the Butser Ancient Farm indicated the loss of emmer grain in harvesting alone using sickles was estimated to be 15-20% (My thanks to the Museum for this information). The Butser Ancient Farm in Hampshire is an experimental archaeology project that has been in operation for 25 years examining British Iron Age farming practices. Widell 2003: 722 citing Kouchoukos 1999: 391 suggest that wastage factors could have been as high as 20-25%.

# 3.4 Workload considerations

This section quantifies the number of agrarian workers needed to produce sufficient crops to feed 100,000 people and follows the sequence of activities that the farmers followed through the process from land preparation to food processing: soil preparation (ploughing, hoeing, clod busting and tilth production), sowing, covering seeds by hoeing or ploughing, irrigation, weeding, harvesting, threshing of cereals, winnowing of cereals, transporting the crops to the processing centre, shelling and drying of pulses, and milling of corn.

The workload (man-days) for each activity of the agrarian cycle is calculated by using the formula: number of hours to complete a particular activity/hectare × (number of hectares ÷ working hours in the day).[287] Work study measurements of pre-1940's A.D. agriculture employing traditional farming practices in Eastern and Southern Europe showed that the number of workers employed exceeded by 40-50% the theoretical workload.[288] This can be easily explained as the agricultural cycle has many peak loads of activity and in most cases moving people from one activity to another and is not easy to organise, particularly if they have to travel.[289] Not all workers have the same range of skills or the physical strength to carry out agrarian activities. Therefore the number of workers required to undertake the workload is always greater than the workload because time must be allowed for days lost through rain, festivals, sickness, familial commitments and other factors unique to the culture concerned. In all the manpower calculations in this thesis it has been assumed that manual workers only worked for 308 days out of 365, equivalent to a loss of 16 % of days available for work in the fields.[290] McMillan's ethnographic study of family

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[287] It is assumed that on average agrarian workers has twelve hours of daylight within which to work. All of this time can not be considered productive as they would have to eat and rest. Time would also be needed to travel to the place of work. This thesis assumes a productive working day of 10 hours.

[288] Rosenstein-Rodan 1943: 202-211.

[289] Folke 1967: 163-173.

[290] Ancient Egyptian festivals centred on procession by land and river, and were celebrated on particular days or series of days in the official year (El-Sabban 2000). Quirke has attempted to collate all the known main festivals amounting to 53 in the New Kingdom (Quirke 2003b). There were probably many more local festivals associated with smaller temples with their own local gods. How many of these were attended by the non-elite and professional classes are open to debate. Certainly festivals such as the Opet festival and the Beautiful Festival of the Valley at Thebes were major events in the Egyptian calendar. This thesis has assumed only 10% of these festivals were attended by the agrarian population to take into account that these festivals were at major temple sites, for example Thebes, El-Kab, Abydos, and therefore out of reach without additional travelling time for the majority

farms in West Africa developed a gender labour index. Using a healthy male as a standard index of one, women were allocated an index of 0.75, teenage boys an index of 0.5, and 0.25 index for teenage girls.[291] The weighted average of this evidence taking into account family responsibilities has been estimated to be 10%. The resulting workload for this study has been increased by the sum of days lost in sickness and festivals plus the labour indexes and this gives a utilisation factor of 74% (see Report 3.29a for the assumptions and analysis). This utilisation factor is used in all the manpower calculations used in AGCALC as illustrated in the following example. If the workload was 200 man-days the number of workers required would be = 200 + (200 × (1-(74÷ 100))) = 252 individuals.

### 3.4.1 Soil preparation

This section starts with a review of the evidence for the methods used for soil preparation in Egypt and dry farming regions. The most likely method was to use a mixture of both the plough and the hoe (see again Figure 3.25). To further the quantitative analysis of manpower requirements two extreme cases will be made:

1. All land is ploughed
2. All land is hoed

Because both cases will be at the extreme limits, combinations of both methods will be used to get a more realistic view of soil preparation in antiquity. It is interesting to note that Lewis' ethnographic study of the Tepoztlán region in Mexico in the 1950's A.D. showed that only 57% of families owned oxen.[292] Again the archaeological record, textual, Egyptian tomb art and ethnographic evidence will be used as evidence.

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of the rural workers. To this must be added the 36 Egyptian weekends, one day each ten days. An average of fifteen days sickness has been assumed taken from ethnographic evidence of rural workers from four districts in Pakistan (Fafchamps and Quisumbing 1998). These assumptions result in a working year of 308 days. See full analysis and assumptions in Report 3.29a in AGCALC.

[291] McMillan 1988: 104 also see Brun 1992: 325-333 and Sokona 1988: 68-89. Janssen's analysis of absence from work of the necropolis workers at Deir el Medina provides additional insight to days lost in New Kingdom Egypt (Janssen 1980b: 127-157).

[292] Lewis 1951: 133, 135, table 28.

One factor that influences the area of land to be prepared for sowing is the area left fallow each year. Dry farming regions practiced fallowing as a means of maintaining the fertility of the soil, allowing animal grazing on the grass and weeds.[293] In addition, crop rotation using legumes fixes nitrogen from the air and returns it to the soil if the roots are ploughed in. However in areas that are prone to severe drought bare fallowing was practiced to conserve the water table in the fallow year. Growing alternate years of green manure or pulses lowered the water table in the fallow year and possibly jeopardising the cereal crop in the non-fallow year.[294] The table below shows the assumptions used in the model for the proportions of fallow land which required ploughing in any given year.[295] Egypt with the fertility renewed by silt deposited by the Nile inundation, would have limited requirement for fallowing and this thesis assumes that fallowing only applied to marginal land. The same assumptions apply in the model to soil preparation by hoeing.

| Region | Percentage of land in any given year left fallow | | |
|---|---|---|---|
| | Marginal | Average | Best |
| Egypt | 50 | 10 | - |
| Cypriot | 50 | 33 | 25 |

**Table 3.12: Percentage of land in any given year left fallow**

## Equipment used for soil preparation

Since ca. 4000 B.C. the symmetrical ard has been in use in the Near East and this type of plough had changed little by the LBA (Figures 3.29-3.30). The plough's handle and crossbar were made of wood, and by the LBA, plough-points made of bronze began to appear. The top of these plough points were hollow and 8-10 cms wide where they were attached to the plough shaft. The other end was forged into a

[293] McGuire 1974: 10 suggests that fallowing has another benefit in controlling salt levels in the irrigated agriculture particularly those around the Euphrates and Tigris. Legumes *Proserpina stephanis* and camelthorn, *Alhagi maurorum* dry out the soil preventing salts to rising through moist soil.
[294] Halstead 1987a: 81-83.
[295] Evidence for the practice of fallowing in the Mediterranean see Jones 1987: 121-122, Gallant 1991: 52-56, and Garnsey 1988: 93-94. In the In the EIA Canaan, land was left fallow every seven years (Borowski 1987: 144-145). In the Hekanakhte letters, in years 8-9, 14 arouras of pasturage was to be converted to growing crops (Allen 2002: 158). It is not clear from the text if the pasturage had been part of a fallowing strategy. Allen notes that modern ethnographic evidence from Egypt suggests that pasturage is not cultivated as part of a fallowing strategy (Allen 2002: 158, footnote 101, citing Ward, P.N. 1993. 'Systems of Agricultural Production in the Delta'. In ed. G.M. Craig, *The Agriculture of Egypt*. Centre for Agricultural Strategy Series; 3: 245. Oxford ; New York: Oxford University Press.

point for ploughing the soil (Figure 3.30).[296] A Kassite seal from Mesopotamia shows an ard in use modified with an attachment to carry out simultaneous sowing when ploughing Mesopotamia (Figure 3.31).

Evidence for the use of yoked oxen in the Aegean and Cyprus can be found from rock art and clay models. Third millennium models of ploughing scenes from Vounous in Cyprus and Nemea in Greece also show the widespread use of oxen controlled by yokes (Figure 3.32).[297] The ard is attested in Egypt from the Old Kingdom in conjunction with the use of hoes for soil preparation (Figure 3.33). The "Beladi" plough used in Egypt at the end of the nineteenth century A.D. closely followed the design of the ploughing ard used in Pharaonic Egypt (Figures 3.34).[298] Ethnographic examples of ards have been attested in Bulgaria in the early Twentieth Century A.D. (Figure 3.35).

## 3.4.2 Ploughing rates

The purpose of this section is to estimate the time taken in Egypt and Cyprus to plough one hectare of land using Classical and Egyptian evidence. The time taken is a function of the number of ploughings required and the time taken for each ploughing. Each time the land is ploughed it becomes progressively easier. The total time taken is also a function of whether the land had been left fallow or not the previous year.

### Number of times the land should be ploughed per agricultural cycle

Columella writing in his first century A.D. treatise *Res Rustica,* recommends four ploughings to prepare the land for sowing wheat if the land the previous had been left fallow.[299] For barley Columella recommends only two ploughings.[300] Ethnographic evidence suggests that three or four ploughings were used for wheat and possibly two

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[296] Borowski 1987: 49-51, Figure 4. The designs of these EIA plough points made of bronze and iron differed little from LBA examples found in New Kingdom deposits in Egypt (See ahead Figure 7.4-7.5)
[297] Karageorghis 1981: 44, catalogue no. 30 and Pullen 1992: 49, Figure 1.
[298] Foaden and Fletcher 1908: 111, Figures 9a and 9b.
[299] Columella *II*.4.4,8,11. All references and following of Columella taken from the translation by H.B. Ash 1948, *Res Rustica*, Vol. 2. The Loeb Classical Library. Harvard University, Cambridge (Massachusetts)
[300] Columella *II*.4.4,9,15.

or three for barley.[301] Ploughing sequentially at right angles to the original furrows seems the usual practice to produce a fine tilth ready for sowing.[302] This thesis assumes two ploughings for barley, wheat, and pulses and an additional light ploughing after sowing to cover the seeds and protect them from birds.[303] An alternative shown in some tomb paintings was to use animals for trampling in the seed (Figure 3.36).[304] Examples of criss-cross ard traces are known in the archaeological record (Figure 3.37).[305]

**Egyptian ethnographic evidence**

Egyptian ethnographic evidence of ploughing rates of uncultivated ground was measured by Foaden and Fletcher using traditional "Nile" ploughs at the beginning of the twentieth century A.D. They concluded that 0.75 feddan/day (0.32 hectares/day) was typical for a pair of yoked oxen with two men controlling them.[306] Foaden and Fletcher did not measure the ploughing rates for the simpler Beladi plough that was more representative of the ploughs shown in Egyptian tomb paintings.[307] To compensate I have reduced Foaden and Fletchers rates to 0.4 feddan/day (0.17 ha/day).[308] With two men per team of yoked oxen the number of men required = 11.8 man-days/ha. For second, third and if necessary fourth ploughings, the 11.8 man-days/ha manpower effort has been reduced proportionally by 50%, 37% and 13% respectively in line with the proportions of Columella.[309] For

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[301] For a cost benefit analysis of the use of ploughs in traditional farming practice in the Aegean see Halstead 1987a: 53-70 and Halstead 1995a: 11-22.
[302] Steensberg 1957: 157-162 and Russell 1988: 120-121, Figure 16. Steensberg proposes an alternative or complementary method to cross ploughing; guiding the ard at an angle to break down the furrow ridges. For the Aegean see Halstead and Jones 1989: 41-55. For Ethiopia see Gamst 1969: 79. for the Yemen see Varisco 1982: 168.
[303] In dry farming regions 10 cms of soil cover is necessary to ensure sufficient moisture content for germination. Five cms would be sufficient in wet land such as post inundation Egypt (Steensberg 1976: 272).
[304] Newberry 1928: 228, Figure 2.
[305] Rees 1981: 14-17, plate 7. Examples found in Celtic contexts are Skaill in Orkney and West Overton Down in Wiltshire.
[306] Foaden and Fletcher 1908: 113, Figure 10.
[307] Figures 3.25 and 3.33-3.34.
[308] This is supported from ethnographic evidence from Kenya where a plough with a simple moulding board and 2 oxen took 25 hours/hectare (Crossley and Kilgour 1983). Assuming a utilised 8 hour working day this equates to a ploughing rate of 0.32 days/ha. A rate of 0.4 hectare/day therefore for a simple Beladi ard plough without a moulding board seems a reasonable estimate for this study.
[309] See Report 3.24a-3.24e and 3.25a-3.25b for assumptions used and analysis. The percentages are in line with those found at the Butser Iron Age museum in Hampshire which carried out ploughing trials using an ard plough with a pair of yoked Dexter Cattle. The author is grateful for discussions on this topic with the staff of the Butser Iron Age Museum.

the ploughing of marginal land previously fallow, the model assumes the same manpower rates as Columella i.e. 15.9 man-days/ha (Report 3.24a). For the full analysis see Reports 3.24-3.25. Summary of the man-days per hectares used in the model for Egypt for two conditions: land had been cultivated the previous year and the land had been left fallow the previous year as shown in the table below.

| Egypt | Land cultivated the previous year | | |
|---|---|---|---|
| | Wheat man-days/ha | Barley man-days/ha | Pulses man-days/ha |
| First ploughing | 11.8 | 11.8 | 11.8 |
| Second ploughing | 5.9 | 5.9 | 5.9 |
| Tertiary ploughing | 4.5 | 4.5 | 4.5 |
| Fourth ploughing | 1.5 | - | 1.5 |
| **Egypt** | **Land left fallow in previous year** | | |
| | **Wheat man-days/ha** | **Barley man-days/ha** | **Pulses man-days/ha** |
| First ploughing | 17.6 | 17.6 | 17.6 |
| Second ploughing | 8.8 | 8.8 | 8.8 |
| Tertiary ploughing | 6.6 | 6.6 | 6.6 |
| Fourth ploughing | 2.2 | - | 2.2 |

**Table 3.13: Ploughing manpower rates for soil preparation in Egypt**

## Columella's evidence

Columella records the time taken to complete three ploughings from fallow land for wheat and barley of 40 hours/iugerum (which equates to 35.2 man-days/ha) and 30 hours/iugerum (which equates to 26.4 man-days/ha) respectively.[310] Columella's evidence below shows that ploughing land that has been left fallow requires significantly more effort than ploughing land that has been tilled in the previous season.

| Columella's manpower rates for Roman Italian estates | Wheat hrs/iugera | Wheat man days/ha |
|---|---|---|
| Breaking fallow land | 20 | 17.6 |
| 2nd ploughing | 10 | 8.8 |
| 3rd ploughing | 7.5 | 6.6 |
| Ridging and sowing | 2.5 | 2.2 |
| **Soil preparation** | **40** | **35.2** |

**Table 3.14: Columella's manpower rates for Roman Italian estates**

## Dry farming ethnographic evidence and assumptions used for Cyprus

Columella's evidence of 35.2 man-days/ha for ploughing land that was previously fallow is within the band of manpower measurements from modern ethnographic

[310] Columella *II*.12.1, 12.2. Conversion units used are: 1 iugera =2522 $m^2$ = 0.2522 hectares. The utilised working day = 10 hrs, assuming of the 12 hrs daylight two are lost from productive work through eating, resting and transporting workers to the field.

studies that used traditional symmetrical ards. In Palestine ploughing rates have been measured using traditional ard ploughs with two oxen in the band 2.7-4.0 man-days/du (26.8-39.7 man-days/ha). In Iran the equivalent measurement was 27 man-days/ha and in the Yemen, using a single donkey was 49.6 man-days/ha for normal ploughing conditions.[311] Columella lies at the lower end of the bands above, which probably reflects the easier conditions experienced on Roman estates than those in the dry farming regions of the Near East. Reflecting these harsher conditions, the model uses the Columella's data but the ploughing rate has been increased by 25%.[312] With the exception of the development of the Roman heavy plough used on large estate farms, it is reasonable to use the evidence of Columella for ploughing manpower requirements as representative of the small ard plough.[313]

Using these assumptions the resulting manpower for planting cereals and pulses are given in the table below.

| Cyprus | Land cultivated the previous year | | |
|---|---|---|---|
| | **Wheat man-days/ha** | **Barley man-days/ha** | **Pulses man-days/ha** |
| First ploughing | 11 | 11 | 11 |
| Second ploughing | 8.3 | 8.3 | 8.3 |
| Tertiary ploughing | 2.8 | 2.8 | 2.8 |
| Fourth ploughing | 2.8 | - | 2.8 |
| **Soil Preparation Total** | **24.9** | **22.1** | **24.9** |
| **Cyprus** | **Land left fallow in previous year** | | |
| | **Wheat man-days/ha** | **Barley man-days/ha** | **Pulses man-days/ha** |
| First ploughing | 22 | 22 | 22 |
| Second ploughing | 11 | 11 | 11 |
| Tertiary ploughing | 8.3 | 8.3 | 8.3 |
| Fourth ploughing | 2.8 | 2.8 | 2.8 |
| **Soil Preparation Total** | **44.1** | **44.1** | **44.1** |

**Table 3.15: Ploughing manpower rates assumed for soil preparation in Cyprus**

[311] Russell 1988: 122-123.

[312] Dijkman and Lawrence 1997: 95-103 has shown that the pulling speed of two white buffalo ploughing across six different soil conditions increased by 17% from softest to the hardest. It is reasonable to assume that the alluvial soil of Egypt probably reflects the bottom end of the scale and hard stony soils prevalent in dry farming conditions reflect the other. The area surrounding the Troodos Mountains probably produced the food to support the miners and is particularly stony making ploughing particularly difficult. To reflect this Columella's data has been raised by 20%. The support relationship between the miners and farmers is covered in Knapp 1997: 46-63.

[313] Pliny *Natural History* 18.171-173 mentions a heavy plough (*plaumoratum*) that was designed for the heavy soils found in Gaul. The technical innovation of this plough was the heavy broad ploughing blade shaped like a spade and the plough itself was supported by a pair of small wheels (see Dark and Dark 1997: 101-103, Percival 1976: 114-117 and Salway 1981: 622-623).

## 3.4.3 Hoeing

Fewer ethnographic studies have been carried out on the man-days/hectare requirements of hoeing compared to ploughing. Haswell measured the time taken to hoe a field once in Gambia using a long-handled hoe and arrived at an average figure of 24.7 man-days/ha from 19 fields.[314] Another FAO study on the use of wooden hoes from the dry farming regions of Tanzania, Zambia and Kenya, on traditional full tillage systems, showed that the typical manpower rates used for weeding, ranged from 14 man-days/ha for the first weeding to 6.5 days/ha on the third weeding.[315] Lewis' study of the Tepoztlán district in Mexico shows that one hectare of bush land could be ready for sowing after 64 man-days had been expended.[316] A summary of the ethnographic data is shown in the table below.

| | | |
|---|---|---|
| **Haswell 1953: Appendices 2 and 6.** | | |
| Average man-days to hoe 1 ha | 24.7 | man-days/ha |
| **FAO 2006 study** | | |
| First hoeing on previously tilled soil | 14 | days |
| Second hoeing | 6.5 | days |
| **Total soil preparation** | **20.5** | **man-days/ha** |
| **Lewis 1951: 155, table 38.** | | |
| Clearance of vegetation | 4 | days |
| Man-days to hoe 1 ha, hoed four times | 60 | days |
| **Total soil preparation** | **64** | **man-days/ha** |

**Table 3.16: Ethnographic evidence for hoeing**

Lewis' findings for the total time spent on soil preparation of 60 man-days/ha are not split into timings for the 4 hoeing cycles required, other than an additional 4 man-days/ha for site clearance using machetes. For the model, the total of 64 man-days/ha has been split using the proportions recommended by the FAO 2006 study (see table below).[317] To compensate for Lewis' data based on modern steel hoes rather than Ancient Egyptian wooded hoes the hoeing workload has been increased by the ratio

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[314] Haswell 1953: Appendices 2, and 6.
[315] Hopfen 1969: 42-44 and FAO 2006.
[316] Although Tepoztlán district in Mexico is a temperate zone, Lewis' hoeing measurements were made on the slopes of the Cerros Colorados and on areas of black volcanic rocky ground where ploughing is not feasible. The land is characterised by rocky outcrops and semi-deciduous scrub forest similar to dry farming conditions of the lower slopes of the Troodos mountains (Lewis 1951: 129-149, Figures 21-22).
[317] Cyprus hoeing workload uplifted for the 1st and 2nd cycles by 30% and 25% respectively to take into account the widespread practice of fallowing to preserve the water table and fertility (see discussion in Section 3.4.1). The Lewis evidence is probably too high for the Egyptian alluvial soil. A sensitivity test (Report 3.26c) shows that reducing the hoeing rate by 20% would only reduce the overall manpower by 2.7%.

| Activity | Egypt | Cypriot | | Egypt modified |
|---|---|---|---|---|
| Clearance + 1st hoeing (based on 1969 FO study) | 26 | 34.5 | man-days/ha | 21 |
| Interpolated | 17.5 | 22 | man-days/ha | 14 |
| Third dig (based on 2006 FAO study) | 14 | 14 | man-days/ha | 14 |
| Fourth dig (based on 2006 FAO study) | 6.5 | 6.5 | man-days/ha | 6.5 |
| **Total soil preparation** | **64** | **77** | **man-days/ha** | **55.5** |
| **Uplifted to compensate data based on steel hoes** | **83.2** | **100.1** | | |

**Table 3.17: Summary of ethnographic data used to determine manpower requirements for hoeing**

## 3.4.4 Sowing, Harrowing and Weeding

### Sowing

Egyptian tomb scenes show that in Egypt cereals were sown by broadcasting (Figure 3.38).[318] This thesis has not been able to trace any experimental archaeology relating to broadcast sowing. An estimate has been made from the following data based on the author's own experimental archaeology for broadcast sowing and are shown in the table below

| | |
|---|---|
| Distance seed can be thrown by sower either side in m | 1 |
| Assume width of field in m | 10 |
| Number of walking lengths to cover this area | 5 |
| Length of field if width is 10 m | 1000 |
| Total length m walked to sow one ha | 5000 |
| Assume speed of walker m/hr | 2000 |
| Time hrs to sow 1 ha | 2.5 |
| **Man-days/ha assuming a 9 hr utilised day** | **0.28** |

**Table 3.18: Estimate time to sow one hectare of land by hand broadcasting**

Russell has cited U.S. Department of Labour records for 1829-1830 in which quotes the time needed to sow was 1.25-1.42 hours/acre (3.1-3.5 hrs/ha).[319] This compares reasonably well with the estimate of 0.28 hrs in the table above. Ethnographic evidence from the Near East suggests that seed may also have been sown as spikelets.[320]

### Harrowing

There were many forms of harrowing used in antiquity. It was done to ensure that seed was covered to protect it from birds and vermin. It had the additional benefit of breaking down any remaining clods, covering the seed in a fine tilth that increased

[318] One of the clearest is that of the Tomb of Paheri who was a nomarch in the reign of Tuthmosis III in Taylor 1895: Plate IV.
[319] Russell 1988: 115 citing *Thirteenth Annual Report of the Commissioner of Labor*, U.S. Department of Labour 1899: 433.
[320] Hillman 1984: 117.

germination rates. For Egypt, harrowing had the additional benefit of levelling the seed bed giving the benefit of more equal water distribution from the inundation.[321] Rakes, hoes, logs or bundles of brush were probably used in the harrowing process as well as mallets to break down large clods.[322] Ploughs in Eygpt may have been used to combine harrowing with sowing.[323] Scenes in the chapels at Meidum suggest that a plough was used to cover the seed after sowing.[324]

The use of animals to cover seeds by trampling has been attested in Egypt. Herodotus noted that pigs were used to trample seed into the ground.[325] This method would have been particularly well suited in the softer soils of the Delta.[326] One Egyptian tomb scene shows a flock of sheep in front of the sower suggesting they were used to trample in the seed.

The model assumes that harrowing was carried out using rakes or brush harrows pulled by oxen. Columella states that together, harrowing and sowing required 20 hrs/iugerum (8.8 hrs/ha) assuming a utilised 9 hour working day.[327] Taking away 0.28 man-days/ha which has been assumed above for sowing this leaves harrowing alone = 8.52 man-days/ha.

## Weeding

Weeds directly compete with plants for moisture, sunlight, nutrients as well contaminating the final crop when harvested.[328] Theophrastus enthusiastically recommended weeding to improve the yield of crops. He warned that a farmer could

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[321] Foaden and Fletcher 1908: 208.
[322] Hillman 1984: 116 and Harpur 1987: 159. Recent ethnographic evidence from South Arabia shows mallets have been used to break up clods of earth in the fields (Doe and Serjeant 1975: 7).
[323] Murray 2000a: 518-519 with references.
[324] Harpur 1987: 161.
[325] Harpur 1987: 162 suggests that some tomb scenes show sheep being used for trampling purposes. One example being the top register of the right half of the east wall of the Middle Kingdom tomb of Djehuty-Hetep at Bersheh show two men sowing with a flock of sheep in front of them to trample in the seed (Stevenson Smith 1951: 324, Figure 2).
[326] Herodotus II.14. Foaden and Fletcher 1908: 107 suggest that cattle would have been too heavy for trampling. Lloyd 1976: 77 supports this view in particular for the wetter conditions of the Delta. Herodotus (II.14) states pigs were used to trample in the seed totally replacing the need for cross ploughing by oxen to cover the seed. See Murray 2000a: 519 for a summary of Egyptian tomb painting evidence.
[327] Columella, *On Agriculture,* II.10.27.
[328] See Arnon 1972: 479, Foaden and Fletcher 1908: 104 describing the competition faced by young plants in particular. For problems associated with the harvest see Willcox 1992: 162.

loose his entire lentil crop if the weed bedstraw was allowed to grow.[329] Wheat and barley suffered from darnel weed if it was not assiduously removed during the growing season.[330] Basler shows the importance of weeding in his ethnographic study with the yield increased dramatically. Without weeding the reverse happened resulting in a significant drop in yield.[331]

| Sowing rate of lentils (kg/ha) | Yield from lentil beds left unweeded (kg/ha) | Yield following weeding in the growing season (kg/ha) | Percentage improvement in yield |
|---|---|---|---|
| 100 | 60 | 642 | 1070 |
| 150 | 90 | 547 | 608 |
| 200 | 62 | 441 | 711 |

**Table 3.19: Ethnographic data showing variation in the yield of lentils with and without weeding**

**Manpower requirements**

The FAO reported their findings and recommendations for weeding with oxen and hoes.[332] The FAO guideline for a pair of yoked oxen to weed a hectare of land growing cereals is on average 7 hours. The FAO recommend that 20.5 man-hours should be allocated for bi-seasonal weeding of pulses using traditional hoeing methods. Both of these recommendations have been incorporated into AGCALC Reports 3.25a and 3.25b.

## 3.4.5 Harvesting

Harvesting of wheat and barley comprises four stages: reaping, collecting, binding and transportation to the threshing area. All four stages appear frequently in Egyptian Tomb paintings in daily life scenes up to the Ramesside period. The Egyptians used curved sickles made of wood with sharp flaked stones attached within a groove in the wooden handle or inset in the jawbone set attached to the wooden handle (Figure 3.39).[333] The reapers hold the ear stems with their left hand cutting them with the sickle in their right hand (Figure 3.40). Tomb paintings show some of the sheaves cut close to the ground and others with just the ears cut.[334] An ethnographic study from

[329] Theophrastus *HP* 8.8.4.
[330] Theophrastus *HP* 8.7.1.
[331] Basler 1982: 143-152.
[332] FAO 2006.
[333] See Murray 2000a: 520-521 for a summary of different designs of sickles together with the problems of interpreting what was reaped, and how it was reaped from the wear of the stone inserts.
[334] In the 6th Dynasty tomb of Hesi at Saqqara, they are cut low (Kanawati 2001: 88: Figure 90). In the Tomb of Sennedjem , Seti I/Ramesses II, only the ears are cut (Hodel-Hoenes 2000: 256, Figure 182).

Gölü Dag in Central Turkey investigated the practice of harvesting barley by uprooting the plant by hand or with an uprooting hook.[335] The complete stems including the ears and seed are bound together, transported by foot or donkey, and stacked into heaps waiting threshing (Figures 3.40-3.42).[336]

## Manpower considerations

### Reaping

Ethnographic reaping rate evidence for steel sickles used on the Greek islands of Amorgos and Karpathos shows that 1.5 man-days/stemma (15 man-days/ha) was needed for harvesting.[337] Akkermans' study of ethno-archaeological and modern evidence produces a reaping rate ranging from 9-11 man-days/ha.[338] Although these studies are useful in providing a lower limit for sickle reaping, the reapers were using steel sickles and so the comparison with LBA agriculture is not directly comparable. The studies are probably unrepresentative of sickles with flint inserts used in the LBA (see again Figure 3.39). Bronze sickles have been found in the LBA archaeological record but they would not be common place because of the metal's exchange value as demonstrated below in Chapters 6 and 7.[339]

Two experimental archaeology studies have been made comparing different designs of ancient sickles used for harvesting from the Neolithic to the EIA.[340] The results of the two studies show that sickles with stone inserts could achieve a harvesting rate of 24.6±3.8 man-days/ha at the 95% confidence limit.[341] AGCALC uses the average reaping time of Steensberg and Korobkova studies as they would be more representative of LBA farming practice.

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However this could be interpreted as the élite tomb owner in the 'field of reeds' wanting to emphasize that the corn was abundant and grew to a great height.

335 Hillman and Davies 1999: 80, Figure 10.7. No work rates have been published for this study and will not be considered in the model.

336 Hillman 1984: 126 suggests that from ethnographic evidence transportation of sheaves was probably carried out at night or early morning when the moisture content was high as this inhibited shedding of grain seed.

337 Halstead and Jones 1989: 47.

338 Akkermans 1993: 216ff. For reaping 75-90 man-hours were expended per ha. This would be workload and assuming a utilisation rate of 0.8 and a working day of 10 hours the manpower requirement would be between 9 and 11 man-days/ha.

339 Bass 1967b: 95, Figure 108.

340 Steensberg 1943 and Korobkova 1981: 325-349.

341 Steensberg 1943: 23 and Korobkova 1981: 340.

**Binding and transporting the harvest from the field to the threshing area**

The model analyses the time taken to bind the sheaves, load and unload the donkey and transport the sheaves to the threshing shed. Ethnographic evidence from Greece shows that 7-12 donkey loads are required to clear the harvest from an area of one stemma (0.1 hectares).[342] Using this rate for the model and assuming that the threshing shed is in the centre of the farm, the man-day requirement for transport is 24 man-days/ha. For the full analysis and assumptions used see Report 3.22a.

**Threshing of grain**

Threshing was carried out on the crops when the sun was at its highest. This facilitated the shedding of seed when the ears were at their driest. Ethnographic evidence from the north-eastern Mediterranean and Egyptian tomb paintings suggest that three methods for threshing were used: hitting sheaves with sticks, oxen and donkeys tethered to a central post to trample the corn (Figure 3.43), and dragging oxen drawn threshing sledge with sharp chipped stones (Figures 3.44-3.45).[343]

**Winnowing of grain**

Halstead and Jones observed the threshing and winnowing process in Amorgos and Karpathos and Simms and Russell in Bedouin villages in Jordan. They show that the process had changed little from that portrayed in Egyptian tomb paintings (Figure 3.46).[344] Winnowing was accomplished initially with a fork, by throwing the seed heads into the air and as the chaff started to separate, paddles were used. The time required to complete the winnowing was directly proportional to wind strength. A coarse and fine sieving was followed by hand sorting for the grain or pulses to be used for human consumption. Nothing was wasted as the chaff and hand pickings were used as animal and chicken feed. Much of the grain for human consumption was ground into flour soon after final hand sorting.

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[342] A stemma is the traditional Greek unit of area equal to 1000 square meters or 0.1 hectares (0.24710 acre).
[343] For ethnographic evidence and experimental archaeology evidence for threshing sledges see Skakun 1999: 203-207. For evidence of this type of sledge in the archaeological record see Ataman 1999: 211-220. Threshing sledges have been found across in all areas of the north-eastern Mediterranean, it has been assumed in AGCALC that they were used in Cyprus in the LBA. No archaeological evidence for threshing sledges has been found in New Kingdom contexts. For Egyptian tomb evidence see Harpur 1987: 166-168, Figure 151 which shows the brandishing of sticks and Eyre 1995: 181 for an example of oxen threshing sheaves of grain corn.
[344] Halstead and Jones 1989: 49-50 and Simms and Russell 1997: 696-702.

## Manpower considerations

Ethnographic studies by Halstead and Jones, Simms and Russell, and Watson have observed the manpower rates for the threshing and winnowing operations.[345] The U.S. Department of Labour 1899 published measured work rates for threshing, winnowing and sacking of wheat and barley.[346] The results of these ethnographic studies have been used in AGCALC and the outcomes have been summarised in the table below.[347]

| Adapted source data Watson 1979: 82. | Wheat | | | | |
|---|---|---|---|---|---|
| | Av. hrs/man | Av. hrs/kg | Av. yield kg/ha | Hrs/ha | Man-days/ha |
| Threshing using 5 oxen | 13.5 | 0.045 | 714 | 32.13 | 3.2 |
| Fork winnowing | 3.5 | 0.0117 | 714 | 8.35 | 0.8 |
| Sieve Winnowing | 1.75 | 0.0058 | 714 | 4.14 | 0.4 |
| **TOTAL** | **18.75** | **0.0625** | **714** | **44.62** | **4.4** |
| **Adapted from Simms and Russell 1997: 700, Table 3.** | **Wheat** | | | | |
| | **Av. hrs/man** | **Av. hrs/kg** | **Av. yield kg/ha** | **Hrs/ha** | **Man-days/ha** |
| Threshing + winnowing | | | | | **5** |
| **Adapted source data US Depart' of Labour 1899** | **Wheat** | | | | |
| | **Av. hrs/20 US bu** | **Av. hrs/kg** | **Av. yield kg/ha** | **Hrs/ha** | **Man-days/ha** |
| Threshing | 13.33 | 0.0246 | 1116.2 | 27.46 | 2.7 |
| Winnowing | 11 | 0.0203 | 1116.2 | 22.66 | 2.3 |
| Bagging | 3.67 | 0.0068 | 1116.2 | 7.59 | 0.8 |
| **TOTAL** | **28** | **0.0517** | **1116.2** | **57.71** | **5.8** |
| **Adapted source data US Depart' of Labour 1899** | **Barley** | | | | |
| | **Av. hrs/30 US bu** | **Av. hrs/kg** | **Av. yield kg/ha** | **Hrs/ha** | **Man-days/ha** |
| Threshing | 15 | 0.0233 | 1166.4 | 27.18 | 2.7 |
| Winnowing | 12.75 | 0.0198 | 1166.4 | 23.09 | 2.3 |
| Bagging | 4.25 | 0.0066 | 1166.4 | 7.7 | 0.8 |
| **TOTAL** | **32** | **0.0497** | **1166.4** | **57.97** | **5.8** |
| Improvement ratio of threshing characteristics of modern free threshing cereals used in modern ethnographic studies over cereal varieties expected in the LBA (Russell 1988: 126) = | | | | | 2.5 |
| | | Uplifted Threshing and winnowing | | | 12.5 |
| | | Baggage | | | 0.8 |
| | | **Total man-days threshing, winnowing, and bagging** | | | **13.3** |

**Table 3.20: Ethnographic data of the man-days required to thresh, winnow and bag wheat and barley**

The results show a reasonable consistency, taking into account all the variables involved. If bagging of the grain is added to Watson's figures his findings are consistent with the others. This model will use the assessments made by the U.S. Department of Trade 1899 as a base number. However grain in the LBA was not free threshing grain and the manpower rate has been increased by a ratio of 2.5:1 to reflect this.[348] The resulting total manpower required for threshing and winnowing is 12.5 man-days/ha.

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[345] Halstead and Jones 1989: 47, Simms and Russell 1997: 696-702 and Watson 1979: 82.
[346] Russell 1988: 125 citing United States Department of Labour 1899.
[347] For a full analysis see Report 3.23a.
[348] Russell 1988: 126.

## 3.4.6 Irrigation

### Egypt's method of exploiting the inundation

Pharaonic Egypt's form of irrigation exploited the natural inundation cycle and natural topography of the Nile valley which allowed the inundation to flow by gravity across the flood plain. The Egyptians took advantage of the slight convex shape of the Nile valley caused by the deposit of silt laid down over many millennia (Figure 3.47). Levees (river banks) artificially raised to 1-3m above the Nile's low water mark gave some level of control as the waters rose during inundation.[349] Remains of ancient levees can still be seen in some parts of the Nile's western bank running parallel to the river.[350] Water spilled out through low points in the levees or deliberately created breaks to form catchment basins that were flooded to a depth of 0.5-2.5m. In Middle Egypt these basins could be very extensive; some were more than 100 sq. km.[351]

To overcome the problem of falling water levels after the initial flood waters had subsided, channels were dug from these basins, to irrigate the fields further away from the river and canals using the shaduf. This method was not efficient as a shaduf could only raise water between one and two metres (Figure 3.48-3.50).[352] Foaden and Fletcher calculated that shadufs in use in the early part of the 20$^{th}$ Century had a lifting capacity of 45,191 $m^3$ per hour.[353] Breasted estimated that a single crop required shadufs lifting 1600-2000 tons of water per acre within the growing period

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[349] A levee can be naturally formed by the deposits of river silt. A dike is defined as an entirely artificial earthen wall, constructed as a defence or as a boundary to prevent flooding from basins to adjacent lowlands thus creating reservoirs of water.
[350] Brewer 2007: 131.
[351] Bowman and Rogan 1999 and Butzer 2001: 184. Some impression of the sheer scale of the land under water in the Pharaonic period was given by the mapping project sponsored by the British Government at the end of the nineteenth century A.D.(Willcocks and Kemeid 1904: 43). Their brief was to map Upper Egypt with particular emphasis on the basin and canal irrigation systems. The largest basins were the Delgâwi basin in the Sohagia system and the Koshêsha basin at the tail of the Bahr Yusef system which covered 194 and 162 $km^2$ respectively. In total there were 103 basins (covering an area of 4,751 $km^2$) on the east bank and 62 basins on the west bank (covering an area of 1,167 $km^2$). The average size of all the basins was 36 $km^2$. In addition there was extensive canal irrigation of 3,046 $km^2$ giving a grand total under irrigation in Upper Egypt of 8,964 $km^2$.
[352] Butzer 2001: 185-186. An Akkadian cylinder seal (ca. 2370-2200) shows the shaduf had been invented much earlier that it's first appearance in Egyptian art in the Amarna period (1353-1335 B.C.) B.C.). This possibly indicates that the idea was copied when the Egypt's hegemony extended to the Euphrates in Mesopotamia in the reign of Tuthmosis III (1504-1452 B.C.). The first evidence for the shaduf appears in the New Kingdom.
[353] Foaden and Fletcher 1908: 173.

of 100 days.[354] When the Nile was at its lowest it could require three shadufs in series to lift the water into the fields from the dykes and basins (see again Figure 3.50).[355] The use of shadufs could have been used for those inundations that fell below the average discussed above in Section 3.1.2.

## Manpower requirements required for Shaduf irrigation

Working from Breasted and Foaden and Fletchers' observations the number of man-days required for irrigation to support wheat production can be assessed as shown in the table below. It is assumed as the annual rainfall in Cyprus ranges from 350 to 400 mm its agriculture would only have an irrigation requirement of % that of Egypt.[356]

| **Irrigation Manpower requirements** | |
|---|---|
| Water requirement (Breasted 1906: 8, footnote 1) tons/acre/day | 18 |
| kg/ha/day | 45,191 |
| Discharge from a typical shaduf (Foaden and Fletcher 1908: 178) m³/hr | 8.4 |
| kg/hr | 8,400 |
| Corrected for lower efficiency in LBA kg/hr | 5,880 |
| Total hours required to water one ha/day | 7.7 |
| Utilised hours worked per day | 9 |
| Irrigation man-power required/day/ha | 0.86 |
| Total irrigation period days | 100 |
| **Man-days/ha for the growing period** | **86** |
| % reduction in water requirement for Cyprus compared with Egypt | 25 |
| **Total man-days//ha for growing season utilised** | **22** |

**Table 3.21: Irrigation requirements for Egypt and dry farming regions**

The manpower requirement of 86 man-days//ha is significantly lower than the irrigation requirement of 72 man-days//ha for flax measured in 1801.[357] A possible explanation for the discrepancy could be that the shaduf observed by Girad required two men to lift the water. As the shadufs that were photographed around the end of the nineteenth century A.D. only needed one man to operate them, the lower figure is used in AGCALC.

[354] Breasted 1905a: 167-168.
[355] Breasted 1905b: Stereograph 35.
[356] Cereals require a minimum rainfall of 200-300 mm per annum (Arnon 1972: 473 and Murray 2001: 513). However rainfall patterns are variable so it is reasonable to assume that irrigation was required in the early growing period.
[357] Richards 1982: Table 2.1, 17 citing source data from Girad 1813: 565-581.

## Dry farming Regions

By the LBA, agricultural systems in the Levant were well advanced with efficient water management, land preparation and harvesting methods well established.[358] Little has been written about the irrigation solutions for the prehistoric Aegean. The date for the introduction of terracing is uncertain but it was probably in use by the end of the LBA.[359]

### Manpower requirements

The limited archaeological and textual evidence for irrigation practices outside of Egypt make the assessment of manpower difficult. AGCALC has assumed that the irrigation effort required in Cyprus was 25% that of Egypt. The rationale for the lower requirement is that some rain falls in the dry farming regions whereas Egypt has almost zero rainfall. Most areas of the Aegean, Anatolia, Northern Mesopotamia and the Levant have 400 mm or greater (see again Figures 3.1–3.4). The same areas have a lower evaporation loss particularly over the main growing period; due to lower mean summer temperatures (see again Figure 3.2).

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[358] Fall 1998: 107-125.

[359] Mee and Forbes have extensively surveyed the Methana peninsula in Greece. Sherds found in some of the terraces show that they have been exploited by farmers since at least the Early Helladic period 2800-2100 B.C. (Mee *et al* 1997: 17).

# 3.5 Milling

Following threshing, grain was milled directly or stored in state silos. Examples of these silos have been excavated in the site of Hattusha (Ḫattuša) in Turkey and in the Ramesseum on the West Bank at Thebes (Figure 5.3).[360]

## 3.5.1 Manpower requirements

**Textual evidence**

Cuneiform tablets from Umna show that 36 women were allowed 10,304 days to produce 60,801 kg of cereals into 67,667 litres of flour. This indicates that the women were allocated 12,983 days to complete the milling if a utilisation factor of 26% is applied (see earlier discussion in Section 3.4).[361] The work actually took 10,715 working days so that an additional 2,679 working days of labour had to be hired. This gives a milling production rate of 6.544 litres of flour/day using a cereal rate of 5.67 kg/day. Another text in the regnal year 48 in the reign of the Neo-Sumerian King Šulgi suggests a daily production rate of 6 litres of flour/day/worker using a cereal rate of 3.850 kg/day/worker.[362] Other texts give slightly higher rates but as they comprise women and men, Grégoire suggests that a milling rate of 7 litres of flour/day/worker using a cereal rate of 4.5 kg/day/worker provides a good average rate for quantitative analysis.[363]

### Ethnographic evidence

Simms and Russell's ethnographic study of villages in Jordan around Petra showed that assuming a 10 hour working day, the milling manpower required to grind the grain for one hectares of land was 37.6 days.[364] Forbes' analysis of Roman milling using hand querns shows that two operatives could produce 2 kg/hr.[365] This milling rate was entered into the model and used to calculate the man-days required to mill

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[360] German Institute of Archaeology, *The Excavations at Hattusha*, created 15/09/2002, last updated 26/6/2004, accessed 25/7/2006, available from http://www.hattuscha.de/eng/themen/05-forschung/silokomplex/forschung-silokomplex

[361] Grégoire 1999: 229 analysis of text A0 5670, *TCL* 5, pl. 4, Umna Š 48/U. 03/23-AS 01/U. 02/ 07.

[362] Grégoire 1999: 229 analysis of text 533 gur 2 bariga 5 ban$_A$: *CT* 3, pl. 19-20, *BM* 18344:0722:zi$_A$ iti-da-bi 8.53; 2, 5, 0 gur.

[363] Grégoire 1999: 229.

[364] Simms and Russell 1997: 700, Table 3.

[365] Forbes 1956: 93.

the harvest output from one hectare of average land. The results show that this milling rate for Egypt and dry farming regions would require 33 and 20 days respectively.[366] The fact that both rates have improved is not surprising as threshing technology has improved since the LBA, and by the Roman period wheat had better free-threshing characteristics. The manpower to mill wheat is given in the table below.

| **Manpower to mill wheat using Roman milling technology** | |
|---|---|
| Flour yield from milling wheat kg/hour | 7 |
| Number of operators | 2 |
| Total number of hours spent by two men to mill 1 kg wheat hours/kg | 0.29 |
| Average harvested wheat yield in Egypt kg/ha | 1156 |
| Average harvested wheat yield in Cypriot regions kg/ha | 714 |
| Total number of hours to mill wheat from 1 ha land in Egypt hours/ha | 331 |
| al no.of hours to mill wheat from 1 ha land Cypriot regions hours/ha | 204.2 |
| **Tot no. of man-days to mill wheat from 1 ha land in Egypt** | **33** |
| **Total man-days to mill wheat from 1 ha land Cypriot regions** | **20.4** |

**Table 3.22: Manpower requirements to mill the harvested output of wheat from 1 hectares of average land**

## 3.5.2 Total man-days required to cultivate cereals and pulses

The man-days required to complete the total process from soil preparation to the milling of grain into flour is the sum of the individual activities.[367] Two cases are considered to summarise the results:

Case 1 calculates the man-days on the assumption that only ard ploughs were used for soil preparation.[368]

Case 2 calculates the man-days required on the assumption that only hoes were used.

[366] The reason dry farming man-days/hectare is lower than Egypt is that the respective wheat yields are lower 714 kg/ha and 1,156 kg/ha respectively (Reports 3.15d and 3.16d in AGCALC).
[367] See Reports 3.22-3.28.
[368] For the case where the land has not been left fallow the previous year, see Reports 3.25b and 3.25c.

# Case 1: Soil preparation carried out with ard ploughs

| Cyprus | Land cultivated the previous year | | |
|---|---|---|---|
| | Wheat man-days/ha | Barley man-days/ha | Pulses man-days/ha |
| First ploughing | 11 | 11 | 11 |
| Second ploughing | 8.3 | 8.3 | 8.3 |
| Tertiary ploughing | 2.8 | 2.8 | 2.8 |
| Fourth ploughing | 2.8 | - | 2.8 |
| **Soil Preparation Total** | **24.9** | **22.1** | **24.9** |
| Sowing estimate | 0.28 | 0.28 | 0.28 |
| Harrowing | 8.52 | 8.52 | 8.52 |
| Weeding using FAO 2006 guideline | 7 | 7 | 20.5 |
| Harvesting | 24.6 | 24.6 | 10 |
| Binding +Transportation of harvest | 24.1 | 24.1 | 24.1 |
| Threshing +winnowing | 12.5 | 12.5 | - |
| Shelling, drying and storing | - | - | 20 |
| Bagging of winnowed grain and pulses | 0.8 | 0.8 | 1 |
| Irrigation | 22 | 22 | 22 |
| **Total arable cultivation** | **124.7** | **121.9** | **131.3** |

| Cyprus | Land left fallow in previous year | | |
|---|---|---|---|
| | Wheat man-days/ha | Barley man-days/ha | Pulses man-days/ha |
| First ploughing | 22 | 22 | 22 |
| Second ploughing | 11 | 11 | 11 |
| Tertiary ploughing | 8.3 | 8.3 | 8.3 |
| Fourth ploughing | 2.8 | 2.8 | 2.8 |
| **Soil Preparation Total** | **44.1** | **44.1** | **44.1** |
| Sowing estimate | 0.28 | 0.28 | 0.28 |
| Harrowing | 8.52 | 8.52 | 8.52 |
| Weeding using FAO 2006 guideline | 7 | 7 | 20.5 |
| Harvesting | 24.6 | 24.6 | 10 |
| Binding +Transportation of harvest | 24.1 | 24.1 | 24.1 |
| Threshing +winnowing | 12.5 | 12.5 | - |
| Shelling, drying and storing | - | - | 20 |
| Bagging of winnowed grain and pulses | 0.8 | 0.8 | 1 |
| Irrigation | 22 | 22 | 22 |
| **Total arable cultivation** | **143.9** | **143.9** | **150.5** |

**Table 3.23: Soil preparation (Cyprus) to grow cereals and pulses using ard ploughs for soil tillage on land cultivated in the previous year**

| Egypt | Land cultivated the previous year | | |
|---|---|---|---|
| | Wheat man-days/ha | Barley man-days/ha | Pulses man-days/ha |
| First ploughing | 11.8 | 11.8 | 11.8 |
| Second ploughing | 5.9 | 5.9 | 5.9 |
| Tertiary ploughing | 4.5 | 4.5 | 4.5 |
| Fourth ploughing | 1.5 | - | 1.5 |
| **Soil Preparation Total** | **23.7** | **22.2** | **23.7** |
| Sowing estimate | 0.28 | 0.28 | 0.28 |
| Harrowing | 8.52 | 8.52 | 8.52 |
| Weeding using FAO 2006 guideline | 7 | 7 | 20.5 |
| Harvesting | 24.6 | 24.6 | 10 |
| Binding +Transportation of harvest | 24 | 24 | 24 |
| Threshing +winnowing | 12.5 | 12.5 | - |
| Shelling, drying and storing | - | - | 20 |
| Bagging of winnowed grain and pulses | 0.8 | 0.8 | 1 |
| Irrigation | 86 | 86 | 86 |
| **Total arable cultivation** | **187.4** | **185.9** | **194** |

| Egypt | Land left fallow in previous year | | |
|---|---|---|---|
| | Wheat man-days/ha | Barley man-days/ha | Pulses man-days/ha |
| First ploughing | 17.6 | 17.6 | 17.6 |
| Second ploughing | 8.8 | 8.8 | 8.8 |
| Tertiary ploughing | 6.6 | 6.6 | 6.6 |
| Fourth ploughing | 2.2 | - | 2.2 |
| **Soil Preparation Total** | **35.2** | **33** | **35.2** |
| Sowing estimate | 0.28 | 0.28 | 0.28 |
| Harrowing | 8.52 | 8.52 | 8.52 |
| Weeding using FAO 2006 guideline | 7 | 7 | 20.5 |
| Harvesting | 24.6 | 24.6 | 10 |
| Binding +Transportation of harvest | 24 | 24 | 24 |
| Threshing +winnowing | 12.5 | 12.5 | - |
| Shelling, drying and storing | - | - | 20 |
| Bagging of winnowed grain and pulses | 0.8 | 0.8 | 1 |
| Irrigation | 86 | 86 | 86 |
| **Total arable cultivation** | **198.9** | **196.7** | **205.5** |

**Table 3.24: Soil preparation (Egypt) to grow cereals and pulses using ard ploughs for soil tillage on land left fallow the previous year**

In summary these results clearly show that the irrigation requirement for the growing season in Egypt strongly dominates the total manpower requirement for the two cases.

## Case 2: Soil preparation carried out by hoeing

| Cyprus | Wheat man-days/ha | Barley man-days/ha | Pulses man-days/ha |
|---|---|---|---|
| Hoeing | 100.1 | 100.1 | 100.1 |
| Sowing estimate | 0.28 | 0.28 | 0.28 |
| Harrowing | 8.52 | 8.52 | 8.52 |
| Weeding estimate | 25.3 | 25.3 | 32.9 |
| Harvesting | 24.6 | 24.6 | 10 |
| Threshing +winnowing | 12.5 | 12.5 | - |
| Shelling, drying and storing | - | - | 20 |
| Bagging of winnowed grain and pulses | 0.8 | 0.8 | 1 |
| Irrigation | 22 | 22 | 22 |
| **Total arable cultivation** | **194.1** | **194.1** | **194.8** |
| Milling | 20.4 | 20.4 | 20.4 |
| **GRAND TOTAL** | **214.5** | **214.5** | **215.2** |

**Table 3.25: Man-days required growing cereals and pulses in dry farming regions using hoes for soil tillage**

| Cyprus | Wheat man-days/ha | Barley man-days/ha | Pulses man-days/ha |
|---|---|---|---|
| Hoeing | 100.1 | 100.1 | 100.1 |
| Sowing estimate | 0.28 | 0.28 | 0.28 |
| Harrowing | 8.52 | 8.52 | 8.52 |
| Weeding estimate | 25.3 | 25.3 | 32.9 |
| Harvesting | 24.6 | 24.6 | 10 |
| Threshing +winnowing | 12.5 | 12.5 | - |
| Shelling, drying and storing | - | - | 20 |
| Bagging of winnowed grain and pulses | 0.8 | 0.8 | 1 |
| Irrigation | 22 | 22 | 22 |
| **Total arable cultivation** | **194.1** | **194.1** | **194.8** |
| Milling | 20.4 | 20.4 | 20.4 |
| **GRAND TOTAL** | **214.5** | **214.5** | **215.2** |

**Table 3.26: Man-days required growing cereals and pulses in Egypt using hoes for soil tillage**

## 3.5.3 Total manpower requirements to feed the population

In Section 3.2 the total calorie requirement to feed 100,000 people was 86,065 million kcals/year. The manpower required to produce these calories in Cyprus was 47,490 man-years and in Egypt 37,205 man-years.[369] Despite more manpower required for irrigation in Egypt than Cyprus this was more than compensated by the higher yield of crops.

[369] The full analysis and assumptions for these manpower numbers are given in Reports 3.28a-3.32d in AGCALC. In this calculation it has been assumed that in Cyprus, when preparing the soil for sowing, 60% was carried out by ploughing and 40% by hoeing. In this calculation it has been assumed that in Egypt, when preparing the soil for sowing, 30% was carried out by ploughing and 70% by hoeing.

# Chapter 4: Cloth Production in the LBA

## 4.1 Introduction

### 4.1.1 Objectives and scope

In Chapter 3 discussion centred on the manpower resources required to feed the population. This chapter analyses the resources and manpower required to support another critical requirement for daily life, namely clothing. It will not include the production of cloth for external trade, mummification and funerary shrouds, furnishing fabrics or the conspicuous consumption desires of the ruling élite. Housing, food and clothing were the three basic requirements that had to be met across all socio-economic groups before the élite could decide how to allocate any surplus to other activities (see again Schematic 2.1 in Chapter 2). These other activities could have been related to the desire for display, value added craft production such as glass and bronze, or support of the state infrastructure. All activities outside of the agrarian sector have to be supported from the harvest surplus. In Chapter 7 a fuller discussion will centre on the importance of surplus manpower to the functioning of the economy.

The evidence will be examined and quantified in these categories:

1. Types of garments worn in the LBA and the area of cloth required to make them.
2. An estimate of the number and types of garments worn by each socio-economic group in LBA society.
3. The annual requirement of cloth for domestic clothing quantified by area.
4. The weight of flax or wool fibre required to make this area of cloth.
5. The area of land and manpower required to produce the fibre and prepare it for spinning.[370]
6. The manpower needed to spin the fibre and weave the cloth.

[370] Comparisons will be made in Section 4.10.5 for the manpower requirements for cultivating and preparing flax fibre ready for growing flax with that required for the husbandry of sheep and preparation of wool for spinning.

## 4.1.2 Methodology

The methodology used for this chapter follows closely the approach used in the analysis of food production in Chapter 3. The end to end cloth production process (growing flax or the production of wool through to the weaving of cloth) used in the LBA is identified and broken down into discrete activities that follow each other in a logical sequence.[371] The time taken to complete each activity is estimated and this enables the number of workers required to be calculated. It is also necessary to estimate the demand for cloth across all socio-economic groups and this is covered in detail in Sections 4.4.3-4.4.6. From this estimated demand the total area of cloth can be determined by multiplying the number of garments required per year by the area of cloth required to make the garments that have been attested to be worn in the LBA.[372] The methodology used follows the seven main stages of cloth production outlined below:

1. The area of cloth required to clothe 100,000 people.[373]
2. The weight of flax or wool fibre required to meet the demand for cloth.
3. The area of land necessary for growing flax or the equivalent size of sheep flocks to provide the required weight of flax or wool fibre required.
4. The agrarian process in growing and harvesting flax or the husbandry of sheep.
5. Preparation of the fibre for spinning
6. Spinning
7. Weaving

### Quantitative analysis

An Excel spreadsheet was developed to model the manpower required to produce the area of cloth needed to provide 100,000 people across all socio-economic groups with domestic clothing. Hereafter the model is referred to as CLOTHCALC.

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[371] See earlier discussion in Section 1.3 related to *chaînes opèratoire.*

[372] The analysis will include blankets for warmth during winter nights. These are considered a necessity as it gets very cold at night throughout the Eastern Mediterranean. In Egypt during the winter temperatures as low as 10°C are common at night and in the desert temperatures approaching freezing point are reached. Current and historic metrological data for Egypt from 1901 A.D. up to the current year can be obtained from National Oceanic and Atmospheric Administration. U.S. Department of Commerce 2007. *Meteorological Reports.* Accessed 24th July 2007. Available from http://docs.lib.noaa.gov/rescue/data_rescue_egypt.html.

[373] This sample size of the population of 100,000 people was used to be consistent with chapter 2. In the demographic studies it is the convention to use a 100,000 sample population as this is considered statistically representative of the whole population. See earlier discussion in Chapter 3, Section 3.2.2.

CLOTHCALC has 13 modules and follows the logical flow of cloth production and the spreadsheet. A copy of CLOTHCALC is given in Appendix 5. This quantitative study will show that the manpower required to produce cloth to clothe 100,000 people across the Eastern Mediterranean, ranged between 10,430 (Cyprus assumed to produce woollen cloth) and 14,659 man-years (Egypt assumed to produce linen cloth).[374]

[374] These manpower numbers are assumed to be full time workers. Cloth manufacture in antiquity used many part-time workers, many of them women. For a comprehensive overview of women's association with cloth production in antiquity, see Barber 1991: 283-298. Taking the highest case, 14,659 man-years, if the workforce was made up of workers who only worked for half a day on cloth production, the number of workers involved in the clothing industry would be 29,318.

# 4.2 Sources of Evidence

## 4.2.1 Archaeological and iconographic evidence

The hot, dry climate of Egypt has provided a wide corpus of cloth, yarn and garments that have survived in LBA contexts which are helpful to this study. The survival or otherwise of a piece of cloth in the archaeological record also depends on the ph of the soil surrounding it. Linen and other cellulose fibres are better preserved in alkaline conditions, whereas animal protein fibres such as wool survive better in slightly acidic environments.[375] One of many examples of cloth remains are those from the Workmens' Village at Amarna which will be referred to frequently throughout this chapter.[376] At the Workmen's Village, 4,962 fragments of linen and woollen cloth have been found in an area of 0.485 hectares.[377] Evidence of cloth and yarn from the regions outside of Egypt live up to the name 'invisibles', given by archaeologists to define organic materials that have not survived in the archaeological record due to the combined effects of moisture, bacteria, insects and rodents.[378] This inevitably means that the overwhelming evidence for cloth production will be Egyptian. However this chapter will show that most of the processes, with the exception of the preparation of fibre prior to spinning thread into yarn, have similarities with the rest of the Eastern Mediterranean regions. The manpower estimates for Egypt, based on linen production with modifications for the sub-processes peculiar to the production of woollen cloth, are in the same order of magnitude for cultures across the LBA Eastern Mediterranean.

Care has been taken when interpreting the evidence of Egyptian garments found in funerary contexts and those depicted in tomb paintings. It is not certain how representative they were of 'Daily Life' conditions, as Egyptian funerary contexts reflect the owner's aspirations about his position in the afterlife. Janssen makes three important points when interpreting Egyptian tomb art as daily life situations.[379]

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[375] Good 2001: 212.
[376] Kemp 2001.
[377] The area of the Amarna Workmens Village was 4,850 $m^2$ (0.485 ha) compared to the larger equivalent at Deir el-Medina of 6,418 $m^2$ (Koltsida 2007: 6-7).
[378] In contrast to Egypt, the Royal Cemetery at Ur has delivered only five fragments of textiles, one of them linen (Potts 1997: 91). Indirect evidence of textiles is found on impressions from Early Dynastic cylinder seals from Fara (Waetzoldt 1972: xix-xx).
[379] Janssen 1975a: 249-250. See also discussion of Vogelsang-Eastwood 1993: 3-4.

1. Tomb paintings often reflected styles from an earlier period and increasingly by the Ramesside period of the New Kingdom they were portrayed in a transfigured state.[380]
2. Artisans and field workers may have had other forms of clothes which they changed into at home which are not depicted in paintings or the archaeological record.
3. Tomb paintings are idealised and do not reflect seasonal or daily temperature conditions.

The evidence for the Cypriot clothing industry is limited but the evidence of loom weights and whorls indicates that the method of producing cloth was similar to woollen and linen production in the Aegean, Mesopotamia, and Egypt. This suggests that the level of technology was the same and in general technologies of the basic crafts did not change significantly in the LBA. This thesis takes the position that the evidence for woollen and linen cloth production from the Aegean, Mesopotamia and Egypt was representative of the methods used by the other regions in the Eastern Mediterranean.

One source of evidence is the different design and number of garments found in intact Egyptian tombs. However, like all funerary contexts the question must be asked how representative they are of daily life. By the time of the New Kingdom the selection of tomb goods was primarily made to reflect the status of the deceased rather than goods essential for his personal use in the afterlife.[381] The pragmatism of the Egyptians meant that they would have realised that their tombs were likely to be robbed. As a result, many of the tomb artefacts had been used in life and were not necessarily the best or newest the deceased had owned.[382] On occasions, articles missed generations and only entered the tombs of later generations when they were worn out or out of fashion.[383] For these reasons, the estimates for the number of garments typically owned by any section of Egyptian society will be based on the practical needs of daily life rather than extrapolated from the numbers found in intact tombs. Eighteenth and Nineteenth Dynasty dress designs will be used to calculate the area of cloth needed to make the garments based on the work of Volsgang-

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[380] 'Transfigured' means the deceased had become an *akh* in the next life having successfully negotiated judgement in front of Osiris and all the appropriate burial ceremonies had been completed (Taylor 2001: 31-32).
[381] See discussion below on the status of cloth in New Kingdom Egypt in Section 4.3.1.
[382] Discussed further in Section 4.3.1 below.
[383] Taylor 2001: 110.

Eastwood.[384] This evidence is taken from tomb paintings and measurements of extant garments taken from intact tombs.[385]

## 4.2.2 Textual evidence

This section reviews the textual evidence for cloth production and trade. Mesopotamian EBA clay tablets show that the scale of the textile industry was extensive, with large numbers of men and women involved in cloth production.[386] Even as early as the late third millennium B.C. the city of Ur had 13,200 weavers and other cities in southern Babylon operated on the same scale.[387] A similarly large scale cloth industry is apparent from Linear B tablets in the Aegean. Large numbers of sheep are noted in Knossos tablets but there was also a substantial linen industry in Mainland Greece.[388] The Na, Ng and Nn Linear B tablets from Pylos show that cloth production from flax was a significant industry.[389] Robkin's quantitative study shows that the palace at Pylos collected 1,239 *SA* units of flax fibre, with an additional 457 units noted but not collected. If both quantities (1,696 *SA* units) were converted into linen cloth, the agricultural sector of the palace would need to produce 49,184 kg of flax fibre.[390] Assuming no losses in spinning, this weight of fibre could produce 152,096 m$^2$ of linen cloth.[391] In Cyprus large numbers of loom weights and spindle whorls suggest that cloth production was a key craft activity.[392]

The importance of the cloth industry to trade in the Ancient Near East is well documented in the large corpus of ancient cuneiform Mesopotamian texts that have survived in the archaeological record and which have been analysed by Crawford,

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[384] Vogelsang-Eastwood 1992a, Vogelsang-Eastwood 1993, and Vogelsang-Eastwood 1994. Although as noted, tomb paintings were symbolic, the actual artistic representations of articles when compared with extant articles are very accurate. This topic will be covered in Section 4.4.2 and uses evidence taken from tomb paintings and measurements of extant garments taken from intact tombs.
[385] The designs of New Kingdom garments will use primarily the work of Vogelsang-Eastwood.
[386] Of particular interest for this chapter are the texts listed in Waetzoldt 1972 and Waetzoldt 1980-1983b: 583-594.
[387] van de Meiroop 1999: 186.
[388] Killen 1964: 13-15, Killen 1993: 209-218 and Halstead 1996-1997: 188. For further discussion on the LBA wool industry see later discussion in Section 4.8.
[389] Ventris and Chadwick 1973: 295, 468-471.
[390] Robkin 1979: 469-470 supports Chadwick 1976: 153 and argues that the *SA* unit referred to in the tablets was flax fibre weighing 29 kg.
[391] Robkin 1979: 474.
[392] Crewe 1998 and Smith 2007. Ivory and bone whorls were excavated at Enkomi (Barber 1991: 62).

Dalley, Gelb, Kuhrt, Leemans and Veenhof.[393] The trade in cloth generally subdivides into two categories: inter-city trade within Mesopotamia, and the trade with foreign countries.[394] Linear B tablet MY X 508 shows that cloth was transported, and possibly traded, between Crete and Thebes (Greece).[395]

Mesopotamian, Linear B and Egyptian texts are biased to large scale textile production and sheep husbandry linked to large royal palace or large temple estates. The extent of smaller domestic production, particularly in rural areas, is poorly represented, though some progress has been made in recent years using archaeo-botanical and archaeo-zoological evidence.[396] Garments and sandals were provided for the state royal tomb workers at Deir el-Medina but were inadequate for their total requirements. To supplement the shortfall the villagers themselves produced clothing on a small scale. This was bartered in the local market.[397]

### 4.2.3 Secondary research

Despite the inevitable questions on how representative the archaeological record and texts were, they do provide glimpses of much of the minutia connected to textile production. Of particular interest to further our understanding of the value place on cloth by LBA society through texts relating to taxation, rations, organisation of labour, trade and the socio-economic relationship of the countryside to urban centres and temples.

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[393] Crawford 1973: 232-241, Dalley 1977: 155-160, Gelb 1973: 3-4, Kuhrt 1998: 16-30, Leemans 1960, Leemans 1968: 171-226; Leemans 1977: 98-99 and Veenhof 1977: 114-115.
[394] Crawford 1973: 233.
[395] Haskell 2003: 151. It could be that the limited evidence for Linear B Mycenaean textile trade is due to the nature of the tablets themselves. Mesopotamian texts were written on damp clay that were then baked in a hot oven and survived better than Mycenaean Linear B tablets that were dried in the sun. The large corpus of Linear B tablets found in Aegean Palace contexts only survived by accident due to the fires raging during the destruction of the palaces. Although the Linear B tablets only provide a snapshot of activity in progress for one period of time, they have a particular value as they reflect a detailed picture of cloth production at that point of time.
[396] McCorriston *et al* 1997: 518-519. A good example of a combined archaeo-botanical and archaeo-zoological approach is the study of the animal bones in MBA IIB site of Tell Jemmeh and its immediate surroundings. The study of animal diet from coprolites and charred vegetable matter together with evidence of animal bones and teeth help produce their life profiles. This showed that 50% of the sheep and goats were slaughtered before their tenth month. From this evidence, the authors were able to deduce the proportions of the flocks used for milk production, meat and wool production (Wapnish and Hesse 1988: 81-94).
[397]Janssen 1988: 19. Deir el-Medina was the Workmens' village that housed the Royal tomb workers and their families in the New Kingdom. The workers are considered to be significantly more 'wealthy' in terms of housing quality, personal tombs and personal items of value than the general populace.

Trying to link the Egyptian and Mesopotamian archaeological record to its textual record is difficult and confusing, as the meaning of many Egyptian and Mesopotamian words relating to physical objects are uncertain. Two scholars help in this area. Steinkeller explains the terminology used in UR III texts relating to woollen textiles and the husbandry of sheep and goats.[398] Waetzoldt has identified the organisation, cloth production processes, and compensation of Mesopotamian cloth production.[399] Another valuable study is Janssen's analysis of the types of garments used by the artisans from Deir el-Medina. Janssen's study of thousands of ostraca led him to conclude that only one Egyptian word *mss,* namely the bag-tunic, can be correlated directly to an attested New Kingdom context. The problem was not an easy exercise in that garments were not tailored but made up of rectangular pieces of cloth and wrapped around different parts of the body. This made it difficult linking garment names to garment types found in the archaeological record.[400] However Janssen has still been able to make a range of suggestions by linking Egyptian words to other known garments.[401] Janssen's published work will be used for estimating the demand for cloth in the New Kingdom in Section 4.4.3.[402] A Near-Eastern perspective of the value of cloth in relation to other goods for Ugarit is provided by Heltzer and Stieglitz, and their work complements that of Janssen.[403]

The work of Barber, Hall, and Vogelsang-Eastwood has been used to determine area of cloth required to make Egyptian garments worn in daily life.[404] Waetzoldt's analysis of Sumerian UR III texts provides valuable information on the spinning and

[398] Steinkeller 1995: 49-70.
[399] Waetzoldt 1972, Waetzoldt 1980-1983a: 583-594, Waetzoldt 1980-1983b: 583-594, and Waetzoldt 1987: 117-142.
[400] Janssen 2008: 2.
[401] Janssen 1975a: 259-264 and Janssen 2008: 21-75 suggest *d3iw* was a kilt/skirt worn by a man or a woman, *sḏw* was a triangular loincloth found together with a kilt/skirt making up a set, *ḥtri n ish* were bands of cloth (sashes) worn crosswise around the upper part of the body, *ḏ3yt* was a cloak, *idg* was a kerchief, *rwḏw* was a shawl, *mrw* for sash, *šndyt* for kilt, *swḥw* shroud, *ifd* for sheet, and *ḥry-kꜥḥt* possibly for shawl thrown over the shoulder. The word *ḥbs* is not a garment but used as a generic word for clothing.
[402] Janssen 1975a: 249-298.
[403] Particularly Heltzer 1978: 17-114 and Stieglitz 1979: 15-23 showing the importance of textiles to the economy of Ugarit and the relationship of textile prices to those in neighbouring countries.
[404] Barber 1982: 442-445, Barber 1991, Hall 1958: 235-245, Hall 1981: 29-37, Hall 1982: 27-45, Hall 1986; Eastwood 1985, Vogelsang-Eastwood 1992a, Vogelsang-Eastwood 1993, Vogelsang-Eastwood 2000: 268-298 and Kemp and Vogelsang-Eastwood 2001. For the Amarna period see Kemp and Vogelsang-Eastwood 2001 and Kemp 2001. See also Reports 4.1a-4.1g in CLOTHCALC with full bibliographic references.

weaving processes, in particular the spinning and weaving rates of cloth producers at the end of the third millennium B.C.[405] Ethnographic evidence of Egyptian and Sudanese spinning and weaving has been provided by Crowfoot.[406] Both Roth and Kemp and Vogelsang-Eastwood's analysis of the construction and operation of Egyptian and Aegean looms, are used in this thesis to work out the different work activities involved in the weaving process.[407]

Killen's analysis and interpretation of Linear B tablets brings alive the scale and importance of the woollen cloth industry linked to the Mycenaean palaces.[408] Burke gives a comprehensive study of the organisation of the Aegean woollen industry which is particularly useful to this study as it covers the transition period from the LBA to the EIA.[409] Halstead adds a new dimension to our understanding of the Aegean wool industry by combining the textual and archaeological evidence with ethnographic evidence.[410]

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[405] In particular Waetzoldt 1972: 91-141.
[406] Crowfoot 1931 and Crowfoot 1954: 413-417.
[407] Roth 1913 and Kemp and Vogelsang-Eastwood 2001: 307-426. In particular Kemp and Vogelsang-Eastwood 2001: 324-426 for a detailed account of experimental archaeology reconstructions of Egyptian Vertical and horizontal looms used to determine methods of warping and weaving in the New Kingdom.
[408] Killen 1993: 209-218, Killen 1964: 13-15, Killen 1984: 49-63, Killen 1985: 241-235 and Killen 1994: 67-84.
[409] Burke 1997: 413-424.
[410] Halstead 1996: 20-42, Halstead 1987a: 53-70, and Halstead and Jones 1989: 41-55 in particular. Underpinning our understanding of the Aegean woollen industry is the ground breaking scholarship of Ventris and Chadwick 1973: 195-231.

## 4.3 Development of cloth production

The purpose of this section is to provide the context for the discussions that follow. The first part discusses the status of cloth in LBA society, the second part examines the value of cloth, and the final part gives an overview of the development in cloth production across the Eastern Mediterranean.

### 4.3.1 Status, value and allocations of cloth as rations

#### Status

The textual and archaeological record of garments clearly demonstrates that the social status of the holder was reflected not only by the number of garments owned but also the quality. The lower the rank the cheaper the materials used, and the quality ranges from coarse textiles similar to modern hessian to exquisite fine linen cloth found in noble and royal tombs.[411] The intact Egyptian Tomb of Kha and Merit shows that Kha had at least 95 garments placed in the tomb.[412] Even in death, cloth was clearly a status symbol. Many of Kha's loincloths were old and worn but they were not thrown away. Instead they were carefully folded to hide any wear and repairs and put on display in the tomb.[413] This maximised the number of the garments owned by Kha in the eyes of guests witnessing the final burial rituals and observing the funerary goods as they were placed in the tomb. The importance and status of clean white linen cloth is reflected in Egyptian religious tests. The rubric to Chapter 125 of the Book of the Dead specifies that the deceased must be pure and clean and clad in white garments.[414]

#### Value of cloth

Bartering in the markets of New Kingdom Egypt used the copper *deben* weight as a value comparator so that goods bought and sold had a value relative to each other.[415]

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[411] Vogelsang-Eastwood 1993: 3, 10-12; Vogelsang-Eastwood 2000: 286. For hessian type cloth with a yarn count of 5 per cm excavated at Amarna, possibly used for workmen's cloaks, see Kemp and Vogelsang-Eastwood 2001: 103-105, Figures 4.15-4.17.
[412] Schiaparelli 1927: 91-93, Figures 63-69. For a more detailed study of Kha and Merits tomb see later discussion in Section 4.4. The items chosen to be included in the tomb were the responsibility of the oldest son who acted as the *sem* priest (Taylor 2001: 191).
[413] Schiaparelli 1927: 92.
[414] Faulkner *et al* 1998: Plate 32.
[415] Value and proto-currencies will be discussed further in Chapter 7, Section 7.6.2.

With this system a piece of cloth, for example, could be related in value terms to grain or any other tradable object by comparing its exchange value with units of account called the *deben*. Jansen argues for 'use' value rather than 'exchange' value and this topic will be returned to in Chapter 7 in the discussion on the nature of the LBA economy.[416]

Janssen's work in analysing the prices of garments at Deir el-Medina gives a guide to the value of cloth and garments against the copper *deben* and other value comparators.[417] An ostracon from Deir el-Medina, the Workmens' Village of the tomb builders of Ramesside kings, shows that a simple linen bag-tunic was valued 5 *deben*.[418] The rate of exchange of one *khar* of grain in the Ramesside period was two copper *deben* and in the New Kingdom the volume of the *khar* was approximately 76.8 litres of grain.[419] Taking the linen bag-tunic as an example, its grain equivalent would be 2.5 *khar* (0.192 $m^3$) of grain. The density of barley is 609 $kg/m^3$ and that of wheat 769 $kg/m^3$. The weights of 2.5 *khar* of barley and wheat would therefore be 117 kg and 148 kg respectively.[420] In Report 3.9d in AGCALC and discussed above in Section 3.2.3 the diet of Egypt was estimated and it was shown that a sample population of 100,000 people would consume 64,807 million kcals/yr of cereals. With a nuclear family of 6 individuals, each family would consume 10,455 kcals per weaned member of the family/day.[421] Volumes of 2.5 khar of barley and wheat have a total number of calories of 388,440 kcals and 491,360 kcals respectively. In summary a linen bag-tunic that costs 5 *deben* was equivalent to a volume of grain that would feed an average nuclear family between 37 and 47 days.

## Evidence of cloth given as rations to workers

Payment with garments or cloth as part of the rations was a common practice in the Near East in the second millennium. A Mari text ca. 1670 B.C. shows textiles were

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[416] Janssen 1988: 14-15.
[417] Janssen 1975a: 249-292, 526.
[418] Janssen 1975a: 9.
[419] Note in the old and Middle Kingdoms a *khar* of grain was set at 48 litres (Quirke 2003a).
[420] Cancelling units leaves dry weight kg = dry density $kg/m^3 \times$ volume litres $\times$ 0.001 $m^3$/litre. For all the steps in this analysis see Reports 4.13a-4.13c in CLOTHCALC.
[421] The full analysis can be seen in Report 4.13c in CLOTHCALC. It is assumed that children up to the age three are breast-fed and therefore do not have to be fed with food grown on the land.

given as part of the cloth rations due to four ox-drivers of Sin-remeni.[422] The Mari tablets (third millennium) and other ancient tablets stipulate that workers were to receive one free garment per year as a part of their wages.[423] Farmers appear in the lists of gifts of precious textiles and metal objects but it is not clear whether they furnished these gifts to the palace, or received them from the palace (ARMT VII 249).[424] Sumerian accounts in the UR III period (2055-1940 B.C.) show that workers were given 2 kg of cloth per annum as part of their rations.[425] Knossos tablets 214 = Ld571ff suggest that palace residents were given a new cloak when their old one wore out as part of their remuneration, in a similar manner to their counterparts at the Palace in Ras Shamra, Ugarit.[426] A Ramesses II stele at Heliopolis, dating to the eighth year of his reign, states that food and oil were to be distributed every 10 days to the stone masons of the king at Heliopolis, and that clothing was to be issued annually.[427] At Deir el Medina garments were distributed at intervals to some of the villagers. The cloth was woven by the inhabitants of the village itself but the raw materials are thought to have been provided by the authorities.[428] Texts in the tomb of the Vizier Rekhmire (ca. 1420 B.C.) show that the mayor of Wah-set paid in tax amongst other goods, two lengths of linen cloth and one linen garment. The Recorder of Abydos paid one garment and one length of linen cloth in a chest.[429]

Another indicator that cloth was highly valued is the evidence of an active second hand market. A divorced woman named Hel from Deir el-Medina (ca. 1190-1187 B.C.) sent her servant to sell a length of worn out cloth probably a cloak or sash in a

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[422] ARMT VII 147 (20-ix-ZL 6'). ARMT *Archives Royales de Mari: Transcriptions et traductions* are a series of Mari texts published over the period 1950-2005. Mari (tel Hariri), was located on the south side of the Euphrates just below the confluence with the Khabur River. It was a major political power c. 1820 – 1750 (Middle chronology) and the archaeological record for this period has produced 20.000 clay tablets, of which 3000 have been translated. They were found in the destruction level of second millennium palace of Zimri-Lim. Its source of wealth was its control of river traffic, it was a centre of fertile irrigation agriculture, and on a major trading route from Babylon that extended from Mari to the city state of Hazor in Northern Palestine and Ugarit on the coast. Of particular interest to this study are the texts in the time of Zimri-Lim (1678-1664) which allow the reconstruction of the accounting practices applied to institutional agriculture (van Koppen 2001: 451-504).
[423] Irvin 1997: 40.
[424] van Koppen 2001: 491.
[425] Waetzoldt 1987: 125. Texts refs required.
[426] Ventris and Chadwick 1973: 314 using parallel evidence from Ras Shamra (Virolleaud 1953: 193).
[427] Kitchen 1996: 195. Stela, year 8, Manshiyet es-Sadr (Heliopolis), Cairo CGC 3504. Line 362.5.
[428] Janssen 1976: 18.
[429] Kemp 1991: 237.

market place on the riverbank.[430] The servant was not able to sell it at the market on the riverbank but it was later exchanged for 1.5 sacks (1.5 *khar*) of grain. Although the selling price was below expectations the cloth was finally exchanged, indicating that even worn out cloth had a value.[431] Cloth itself had more than a utilitarian role, as it could be used as a form of currency, as security against a loan, and given away as a mark of honour.[432]

A measure of the importance of textiles in the Near East was the frequency with which they were used as tribute and gift exchange. Mari high officials and members of the royal family paid regular revenues of textiles, silver, and animals to the king.[433] In the Amarna letters the Alashiyan king requested clothing as well as furniture, oil, and horses (EA 34: 18-28). Tarkhundaradu the King of Arzawa received linen together with gold, oil, vessels and furniture from the Egyptian King as part of the marriage negotiations of his daughter (EA 31: 23-38).[434]

## 4.3.2 Developments in cloth production

This section will give a contextual overview of the development of cloth production across the Aegean, Mesopotamia, and Eastern Mediterranean. The first direct proof of weaving can be dated to early seventh millennium B.C. At this time the process was very similar to basket-making. Impressions of plain weave and basket weaves were left on samples of clay at Jarmo in north eastern Iraq (Figure 4.1). Plain weave, sometimes called tabby weave, uses a single warp and weft while basket weave uses a double warp and weft.[435] Increased complexities of plain weaves were developed in the second half of the seventh millennium B.C. as demonstrated by textile and tape

[430] Janssen 1980a: 1-27.
[431] McDowell 1999: 43-44, 84 commentating on Ostracon UCL 19614. Citations referenced in McDowell 1999:246 endnote 18. See also discussion Janssen 1982: 109-115.
[432] Meskell 2002: 109-110; 162-163, Eyre 1998: 179; 182, Vogelsang-Eastwood 1993: 2.
[433] van Koppen 2001: 466. These payments in Mari texts are designated with the words *biltum* and *igislim* indicating they are gifts presented to the King.
[434] The Kingdom of Arzawa was in South-West Anatolia and its King Tarkhundaradu was corresponding with Amenhotep III of Egypt sometime between ca. 1391-1353 B.C. This thesis will use the letter and numbering system (e.g. EA 31) of the Amarna letters as used in the translations by Moran 1992.
[435] The warp threads run vertically through the cloth. The weft threads are woven horizontally in and out of the warp threads to produce cloth.

fragments from Çatal Hüyük and Nahal Hemar.[436] Among the variations were coarse yarn threaded one way and fine thread the other, variation in the number of warp treads up to four times that of the weft per unit length, and weft wrapping and twining (Figure 4.2).[437]

The introduction of the horizontal loom followed by the vertical loom significantly increased productivity. Horizontal or 'ground looms' have the warp stretched horizontally between two beams that were pegged to the ground. Vertical looms are sometimes shown at an angle to a wall. The warp is not stretched between two beams; instead they are attached to a top beam and stretched using weights, commonly clay or stone, which have holes in the centre to facilitate tying. Numerous weights have been found in the archaeological record and provide dating criteria for the introduction of vertical looms.[438] See Figure 4.3 showing the design and operation of horizontal loom.[439] Horizontal looms are first attested in the Near East by a seal from Susa dated to the end of the fourth millennium B.C. (Figure 4.4). In Egypt horizontal looms are attested from the Badarian period (4300-3900 B.C.) as shown by a painting on a dish now in the Petrie collection.[440] One of the best representations of the horizontal loom is from the Middle Kingdom tomb of Khnumhotep at Beni Hasan (BH3) Dynasty XII ca. 1985 B.C. (Figure 4.5).[441] The larger vertical looms were introduced in the New Kingdom period and their design and operation are shown in Figure 4.6.[442] The tomb of Thutnefer at Thebes (TT104) ca. 1478-1479 B.C. has a detailed tomb painting of a vertical loom (Figure 4.7).[443]

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[436] Çatal Hüyük is a Neolithic site in central Anatolia of 10,000 inhabitants, southeast of the modern city of Konya. Nahal Hemar is a Neolithic cliff top settlement near the Dead Sea in Israel.

[437] Burnham 1965: 165-174. Weft wrapping is where the weft thread is wrapped around the warp tread instead of over and under the next. Weft twining uses two wefts that run in parallel. One weft thread is passed over the warp thread and the other passes the warp thread. See Figure 4.2 for illustration of weft wrapping and twining. Samples of weft wrapping and weft twinning from Nahal Hemar are dated to ca. 6500 B.C. and those from Çatal Hüyük to ca. 6000 B.C. Weft wrapping and weft twining should be seen as an intermediate stage of development before true weaving as characterised by the introduction of the shuttle in looms (Barber 1991: 131).

[438] Ellis 1976: 76-77.

[439] Wilson 1933: 6, Figure 1 and 2.

[440] The collection number is UC15766.

[441] The Egyptian artistic convention portrays an object in an orientation that best describes its form and function. The plan view of the horizontal loom is drawn vertically so as to show its design and the two operators weaving. Females are always shown operating horizontal looms (Figure 4.5) while vertical looms are shown operating by one or two men generally seated (Figures 4.6-4.7).

[442] Wilson 1933: 6.

[443] The operation and manpower required to operate the horizontal and vertical looms are discussed later in Section 4.10.1.

One factor that significantly influenced the development and practices used for cloth production was the choice of fibre, between flax and wool. Both provide hard wearing cloth but the characteristics of both materials influenced how the respective fibres were prepared for spinning and the manpower required to produce them. The preparation of flax ready for spinning takes longer than wool.[444] However growing flax, with its requirement for moist soil and constant weeding, is more demanding in terms of manpower than the husbandry of goat or sheep flocks. It was for these reasons that Egypt with good water supplies but minimal grazing land concentrated on flax, rather than in wool.[445]

The earliest attested sample of linen weaving in Egypt is from a fifth millennium deposit in the Fayum.[446] Scraps of linen cloth, mainly plain open weave, have been salvaged from later Badarian levels at Mostagedda Middle Egypt.[447] The oldest, most complete ancient garment is a First Dynasty pleated and fringed dress from Tarkhan (Figure 4.8).[448] It has a light lacy texture due to the weave having only 6 wefts per inch compared with a warp count of 72 warps per inch.[449] A measure of the extraordinary capabilities of the Old Kingdom weavers is a sample of linen from Heliopolis that was woven with a more usual warp count of 200 warps per inch.[450] For comparison with modern linen production, a fine linen pillow case has a warp count of 100 warps per inch.[451] A Middle Kingdom innovation was to loop the weft above the surface to give a noticeable textured characteristic to linen cloth as shown in the Eleventh Dynasty sample from Deir el-Bahri ca. 2040-1991 B.C.(Figure 4.9).[452]

Introduction of coloured yarn to add stripes to cloth was common from the late 18$^{th}$ Dynasty onwards. Egyptian funerary depictions of Syrians and Canaanites show

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444 This will be discussed in detail in Sections 4.7 and 4.8 respectively.
445 This will be discussed in detail in Section 4.5.2.
446 Caton-Thompson and Gardner 1934: 46 and Plate 28.3.
447 Midgeley 1937: 61-63.
448 The dress was found in Mastaba tomb 2050 by Petrie.
449 Barber 1991: 146.
450 Midgley 1915: 50.
451 Barber 1991: 148, footnote 1.
452 Winlock 1942: 206 and Plate 37. The sheet is now in the Egyptian Museum in Cairo (museum number 813). Other examples are the weft looped towels and a weft looped blanket on Merits bed in the Eighteenth Dynasty Tomb of Kha and Merit at Deir el-Medina ca. 1350 B.C. (Schiaparelli 1927: 16, Plate 105). For a more detailed description of the process to make weft looped and pile textiles see Bellinger 1955: 1-8.

envoys bringing tribute to Egypt wearing elaborately patterned woven clothing. This probably indicates that dyeing was an established craft across the Near East.[453] Flax is not an easy material to dye due to the hardness of the fibre surface.[454] This may explain why the vast majority of Egyptian linen was left its natural colour. Dyes available to Egyptian cloth producers in the LBA were restricted to blues, red and yellow ochres.[455] An earlier technique for colouring textiles was to paint them, and examples have been found across the Near East from ca. 3000 B.C.[456] From these simple beginnings and the limited palate of dyes available, a wide corpus of textile patterns developed particularly in the Nineteenth Dynasty. Increasingly complex patterns were further enhanced with beads sown on or strung on the weft, bead netting, fringes, embroidery and other decorative techniques.[457] This blossoming of decoration was probably influenced by Egypt's increased contact with other cultures which had begun with the Near Eastern campaigns of Tuthmosis III ca. 1458 B.C. to the end of Ramesses III reign in 1163 B.C.[458]

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[453] Examples of Syrian patterned cloths are shown in the Egyptian tombs from the 15th–late 18th Century B.C. Pritchard classified Syrian garments into four types. Pritchard's example of Type C is one of a Syrian with a ankle-length patterned tunic with a hip wrap that circled the body (Pritchard 1951: 39, Typology C). Wachsmann 1987: 4-9 is less certain that tomb depictions of foreigners in general can be taken as accurate representations. Wachsmann proposes that Egyptian artists practiced hybridism where the subjects humans, objects or entire scenes, were amalgams of two or more separate entities (Wachsmann 1987: 4). Hartwig 2004: 74-75 makes a similar point that Egyptian artists' primary concern was to ensure the object, person or scene looked "foreign". Gilroy 2002: 35 has suggested that foreigners were shown terrified, clownish and undignified to contrast with Egyptian officials who were portrayed with dignity and physical beauty. However as Pritchard 1951: 41 suggested, with the increased contact with foreigners, it would be surprising if this type of tunic did not have some resemblance to reality. This thesis takes the position that embroidered and woven coloured textiles were available to the elite in the Levant, at least in the LBA.

[454] Schick 1998b:22.

[455] Red ochre pigments uses limonite or hematite that has been heated to high temperatures (Schick 1998b: 63). The first Egyptian sample is from the Middle Kingdom where a fragment of red linen had been used as a mummy wrapping (Schick 1998b: 64 and Wouters. J., L. Maes, and R. Germer 1990: 89). The Identification of Haematite as a Red Colorant on an Egyptian Textile from the Second Millennium B.C. *Studies in Conservation* 35: 89-92). Red cloth has been attested in Mesopotamia before 2500 B.C. at the Royal Cemetery at Ur and in the Levant from the Cave of the Treasure in Nahal Mishmar (Barber 1991: 231, 223-224).

[456] Koren 1998: 101. Two coloured cloths, one with four blue stripes, along the selvage, and the other with two pink and two blue stripes indicate that coloured patterns could have been introduced into Egyptian cloth as early as the late Fifth Dynasty, probably in the reign of King Unas (2356-2323 B.C.). The two Old Kingdom samples reside in the Boston Museum of Fine Arts, museum number TL 2869.1. Barber 1991: 149 warns that the Old Kingdom samples may have been miss-dated with the less rigorous excavation techniques of the 19th Century A.D.

[457] Barber 1982: 442-445 and Barber 1991: 156-161, Plates 1-4.

[458] With the death of Ramesses III who had successfully defended Egypt from attacks by the Libyans and sea peoples.

# 4.4 The area of cloth required for clothing

This section calculates the amount of cloth required to clothe 100,000 people.[459] The area of cloth required to be made per annum for any culture is a function of:

1. The socio-economic profile of the culture and the proportion of the population within each of the socio-economic groups.
2. The range of garments worn by each socio-economic group.
3. The number of garments owned within each socio-economic group.
4. The unit area of cloth required to make up each type of garment.
5. The rate at which garments have to be replaced due to wear-and-tear.

The evidence for the range and design of garments worn in Egypt far exceeds that from the other regions of the Eastern Mediterranean and the Egyptian evidence will be prime sources of data used in this section.[460] However Section 4.4.2 will demonstrate that the Egyptian data is probably applicable to the other regions of the Eastern Mediterranean.[461] The demand for cloth for funerary purposes and the conspicuous consumption of the élite are not considered. This requirement for cloth would be one of the choices made by the élite when allocating surplus after the need for food and domestic clothing had been satisfied.

## 4.4.1 The socio-economic profile of LBA society.

To further develop this line of enquiry five socio-economic groups have been chosen that seem best represented in the textual, artistic and archaeological evidence of LBA society:

1. Royalty, nobles and high élite controlling the major offices of state.

2. Senior officials working for these state offices.

3. Professional class (scribes, architects, engineers).

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459 By convention in demographic studies a population sample of 100,000 individuals is deemed representative of the whole sample.
460 See earlier discussion in Section 4.2.
461 The analysis in CLOTHCALC will use a demographic sample of 100,000 individuals based on the Coale-Demeny Model West, level 2 model to ensure consistency with the analysis used in Chapter 3 relating to agriculture. For earlier discussion on the rationale for the demographic model chosen see Section 3.2.

4. Lower administrators and skilled workers.

5. The agrarian workforce.

For convenience, these groupings will be used throughout this thesis and in the model CLOTHCALC and referred to as socio-economic groups 1-5. For the purposes of this study the term 'élite' will refer to socio-economic groups 1-3.

## The rationale for using literacy to define the élite

A rationale must be developed to estimate the number of individuals making up each social-economic group in LBA society. In any society the size of the élite is a small proportion of the total population. Baines suggests that for Egypt, literacy levels give some indication of the proportion of the total population that can be considered members of the élite.[462] Defining the threshold of literacy itself in an ancient context is not without its difficulties as succinctly summarised by Baines:

> Several levels of literacy are possible: reading, of various degrees of competence; reading and the physical ability to write; reading and narrow composing ability, especially in accounting; reading and the full ability to compose texts; and, at the other extreme, the carving of signs with limited reading ability, which was probably the condition of many relief sculptors.[463]

Linear A and B tablets from the Aegean, early administrative writings from Mesopotamia and many of the ostraca from Deir el Medina are primarily tabular accounting records and not prose. While they give invaluable evidence of the structure and the economy of LBA society they do not necessarily indicate widespread literacy.[464] Comprehension of lists, particularly those that have numeric signs can extend to a section of the population far beyond what is normally accepted as the threshold of literacy.[465] So far no literary or religious texts have been found in the Aegean archaeological record.[466] In contrast in Mesopotamia and Egypt literary writing is known from 2600 B.C. In New Kingdom Egypt hieroglyphic texts are

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[462] Baines 1983a: 572 -599, Baines 2007: 49-50, and Baines and Eyre 1983: 65-96.
[463] Baines 2007: 50.
[464] For Aegean administration texts see Bennet 1985: 231-249, Killen 1985, Ventris and Chadwick 1973: 241-305 and Tzachili 2001b: 167-175. For Mesopotamia see Green 1971: 345-372. For Deir el-Medina see Janssen 1975a and McDowell 1999: 59-61 particularly discussion on laundry lists.
[465] Berk 1996: 215–235.
[466] For the Aegean case it is possible that due to the use of sun baked tablets, as opposed to Mesopotamian fired tablets, only those from the administration centres of the palaces that were destroyed survived due to the accidental firing. It is a possibility that literary/religious texts could be written, but have not survived because they were not artificially baked.

found in monumental inscriptions, cursive hieroglyphic script in scribal training and official religious texts, hieratic script in literary, religion and magical texts as well as extensive use of hieratic script in daily use in business and administration transactions.[467] Despite the abundance of surviving evidence, Baines and Eyre estimate that only one percent of the population was fully literate.[468]

The evidence from Deir el-Medina suggests some elementary level of literacy had been developed by skilled craftsmen, certainly sufficient to recognise lists of common day to day things.[469] The evidence for women's literacy is only circumstantial. Some scholars in the past have interpreted the Middle Kingdom Egyptian word *seshet* as the female form of the title for scribe *sesh*.[470] More recent scholarship prefers *seshet* meaning 'painter of the house' or 'cosmetician' rather than female scribe.[471] In a small number of New Kingdom tomb scenes, a scribal kit is shown below the chair of the wife seated with her husband or son. Robins suggests that this did not signify female literacy but gave a balanced picture.[472]

## Using literacy to estimate the size of socio-economic groups 1-3

Baines proposes that the literacy levels for males and therefore the élite of LBA society were no higher than one percent and may have been as low as 0.33%.[473] Female literacy was considered to be so low that for this study this factor can be ignored.[474] If it is assumed that the literate were one percent of males over the age of 15 the number of literate males would be 540. With an estimated average family size

[467] Baines 1983a: 581-583.
[468] For description of scripts and text types in the New Kingdom see, Table 3. For the rationale for the one percent literacy level see Baines and Eyre 1983b: 65-72.
[469] For lists associated with daily life activities see particularly McDowell 1999: 53-90.
[470] Ward 1986: 16-17.
[471] Robins 1993: 110.
[472] Robins 1993: 113.
[473] Baines 2007: 49, 64-67. Baines assumes that most tomb building was carried out by elite males within the age range 30-45, a span of 15 years. In the Old Kingdom the numbers of inscribed tombs were approximately 4000 in number. The length of the Old Kingdom was 430 years so approximately 10 per year would have been started per year. The number produced over the 15 year span would be $15 \times 10 = 150$. This must be increased to take into the tombs of those who died before the age of 30 and the number of tombs un-inscribed which Baines suggestion is twice the number of inscribed tombs. The amortised number of tombs would therefore = 150 (inscribed tombs) + 150 × 2 (tombs of those who died before 30 and un-inscribed tombs) = 450 which he rounds up to 500. The population of the Old Kingdom has been estimated to one million. Assuming these tombs were male elite with an average family size of 7 then this would equate to the elite = 3500 or 0.35%. Baines considers that this percentage could be applicable to the New Kingdom (Baines 2007: 68).
[474] Baines 2007: 67-68.

of 5.5, the number of literate males and their families would total ca. 2,970 per 100,000 population.[475] With the low estimate of male literacy at 0.33% literacy level this becomes 990/100,000 population. For this study a one percent literacy rate has been assumed in CLOTHCALC.

## Allocating the élite to socio-economic groups 1-3

The next stage is to allocate the 2,970 literate men and their families to their appropriate socio-economic groups 1-3. This is relevant as the quantity of clothes owned per family varied, reflecting the hierarchical nature of LBA society as a whole.[476] To estimate the number that could be allocated to each group a number of indicators have been used such as tomb sizes, goods found within them, housing, titles of tomb holders within the Egyptian administration. Tomb size and the position in the necropolis give general indications of the social position of the tomb owner within socio-economic groups 1-3.[477] I have estimated the percentages of the élite within socio-economic groups 1-3 using a number of factors, such as the size and complexity of these élite tombs with their administration titles given in the tomb autobiographies, and linked this to Balanda's extensive analysis of the Egyptian administration titles and O'Connor's organisational chart of the New Kingdom administration (Figure 4.10).[478] A summary showing the resulting allocation of the 2,970 strong élite into socio-economic groups 1-3 is given in the table below.

| Socio-economic groups | %split by S-E groups | Literate males | Elite popul-ation |
|---|---|---|---|
| Socio-economic group 1 | 5 | 25 | 138 |
| Socio-economic group 2 | 10 | 55 | 303 |
| Socio-economic group 3 | 85 | 460 | 2,530 |
| | 100 | 540 | 2,970 |

**Table 4.1: Allocation of the élite population into socio-economic groups 1-3**

[475] The full analysis is given in CLOTHCALC Reports 4.2a-4.2b. As discussed in Section 3.2.2 54.34% of the ancient population would be aged 16 or above (i.e. 54,340 adults/100,000 population).
[476] To be discussed below in Section 4.4.3.
[477] A good example is Amarna where the 25 elite tombs (not all completed) were built in a necropolis close to the tomb of Akhenaten (Reeves 2001: 131-137). There were always exceptions to this rule for any period, Horemheb and Maya both built their tombs at Memphis in the Amarna period (Martin 1991: 29-30).
[478] In total Balanda has identified 448 titles and 75 different government departments. A full concordance is given in Balanda 2003: 567-595. I have adapted O'Connor's chart showing my estimate as a coloured overlay for socio-economic groups 1-3 (O'Connor 1983: 208, Figure 3.4).

## Rationale for the size of socio-economic groups 4-5

With the élite estimated to be 2,970 per 100,000 population this makes the numerically largest socio-economic groups 4-5 equal to 97,030 individuals per 100,000 population.[479] Of this number it is assumed that there were 10,000 individuals made up of skilled craftsmen and their families. These were allocated to socio-economic group 4 leaving 87,030 individuals in socio-economic group 5.

| Socio-economic groups | No. of families | Popul-ation |
|---|---|---|
| Socio-economic group 1 | 25 | 138 |
| Socio-economic group 2 | 55 | 303 |
| Socio-economic group 3 | 460 | 2,530 |
| Socio-economic group 4 | 1,820 | 10,000 |
| Socio-economic group 5 | 15,820 | 87,030 |
| | 18,180 | 100,000 |

**Table 4.2: Estimate of the number of individuals correlated by socio-economic group for Egypt in the LBA (n=100,000)**

# 4.4.2 Designs of LBA garments

Having estimated the number of individuals within each socio-economic group above, this next section will review the evidence for commonality in the design of garments. The design dictated the demand for cloth across all regions of the Eastern Mediterranean. If there was commonality, then it is reasonable to assume that the area of cloth required to make up extant Egyptian garments could be used to calculate a similar wardrobe for other regions of the Eastern Mediterranean. From necessity the time period used for this evidence extends beyond the LBA. However, although styles seem to differ when the patterns are translated, in terms of the areas of cloth required they are still comparable. It is recognised that the ambient temperatures in North-Eastern Mediterranean are significantly lower than Egypt. To a certain extent this is taken into account by the predominant use of wool outside of Egypt. The fibre structure of wool contains air which makes it naturally warmer (see later discussion in Section 4.9).

Many of the types of garments worn in New Kingdom Egypt have survived in the archaeological record and are on display in Egyptian collections. They have been

[479] It is not intended that the number 97,030 can be calculated to the level of accuracy the number suggests. Rounding has not been used in section 4.4 to ensure integrity of numbers across spreadsheets and the main text.

examined and measured by Vogelsang-Eastwood, Hall, and Johnstone.[480] Where there is a gap in the archaeological record, Vogelsang-Eastwood has used the evidence from tomb paintings, pot decorations and statues. From this data, patterns of all the known garments worn in the New Kingdom have been produced. The amount of cloth needed to make the garments has been calculated from these patterns.

To test the hypothesis that there was a commonality in demand for cloth across regions I have used the work of Jones, Pritchard, Houston and Schick.[481] Both Jones' work on developing patterns for the Aegean, and Houston's for Mesopotamia and the Levant have been particularly useful as their approach is similar to that of Vogelsang-Eastward, Hall and Johnston's, making comparisons easier. Here the evidence is primarily from frescoes, seals, statues and pot decoration as so few textiles have survived in the archaeological record.[482]

## Egypt

The main categories of garments worn were kilts and aprons by men and skirts and dresses for women. Those worn by both sexes were loin cloths, cloaks, sashes, shawls, kerchiefs and blankets. Kilts came in three styles, long, short and sash (Figure 4.11). Female skirts came in two styles, long and short. Dresses were either a simple V neck or a wrap-around design. Cloaks were also of a wrap-around style for both sexes (Figure 4.12). The complexity of these designs is demonstrated by the typology study of 20 Ramesside complex wrap-around designs by Hoffmann and Hoffmann (Figure 4.13).[483] Figures 4.14-4.15 is Vogelsang-Eastward's suggestion as to how sash kilts and dresses could have been produced from simple rectangles of cloth wrapped around the body. Despite the number of wrap-around variations, the

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[480] Vogelsang-Eastwood 1992a, Vogelsang-Eastwood 1993: 12-176, Hall 1981: 29-37, Hall 1982: 27-45, and Johnstone 2007.

[481] For the Aegean I have used the patterns produced by Jones 2000: 37-28, Jones 2003: 441-450, and Jones 2005: 707-716. For Mesopotamia I have used Houston 1954: 115-131. Although Houston's work was published in 1954 the garment patterns created from Mesopotamian and Levantine iconography is still valid for the purpose used in this thesis. To supplement the Levant I have used Pritchard 1951: 36-41 and Pritchard 1954. For the rare examples of extant garments found in the Levant I have used Schick 1998a.

[482] The notable exceptions are the garments found in the Late Fourth Millennium-Early Third Millennium Canaanite 'Cave of the Warrior' (Schick 1998c: 6-22).

[483] Hofmann and Hofmann 2004: 167-169.

area of cloth can be approximated to those suggested by Vogelsang-Eastwood, namely 2.5 x 0.6 m for sash kilts, 3.05 x 1.075 m for simple wrap-around dresses, and 4 x 1 m for the most complex dresses.[484]

**The evidence for male kilts**

Pritchard's work on Asiatics portrayed in Egyptian tomb scenes show Asiatics wore wrap-around kilts (Figure 4.16A).[485] LB III Cypriot bronze figurines show men wearing knee-length kilts decorated with wide ornamental bands similar to those shown in the tomb paintings of Rekhmire.[486] The fresco at Xeste 4 (Akrotiri), shows a man with a patterned complex wrap-around kilt. Similar kilts are shown in the Egyptian tomb of Rekhmire at Thebes representing the Keftiu bringing gifts to the vizier. By this date, they may have been Mycenaeans and not Minoans (Figure 4.17, 2).[487] Even if the only direct or even indirect contact with the Mycenaeans was through the western trading emporium of Ugarit, their culture may have become known to the Egyptians. It is on this basis that I think it is reasonable to say that the Mycenaeans wore kilts.[488]

Houston's study of Mesopotamian costume shows that kilts were worn at least in the period ca. 2500 B.C. The stele of Naram-Sin now in the Louvre shows a warrior dressed in a kilt with a sash over the left shoulder and tied around the waist (Figure

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[484] Vogelsang-Eastwood 1993: 101, 181.
[485] Pritchard 1951: 36-41 and Pritchard 1954.
[486] Buchholz and Karageorghis 1973: Plates 480-481.
[487] For the purposes of this study I have assumed that Mycenaeans wore kilts similar to those portrayed in Rekhmire's tomb. The fact that the kilts were over painted probably reflects an update in the pattern books used by the tomb artists (for more commentary on the use of pattern books see Wachsmann 1987: 121-123, plates XXII –A). These changes may have followed direct or indirect contact with Mycenaeans requiring a change in the portrayal of Aegeans after the collapse of the Minoan culture ca. 1450 B.C. For a more in-depth discussion on changes made to the depictions of Aegean figures on tomb walls in the 18th Dynasty tombs see Barber 1991: 331-338, Wachsmann 1987: 43-48; 105-111; 121-125, and Vercoutter 1956: 243-250, 283-284, plates XIV-XIX. The date of the collapse of the Minoan culture is of interest to the scope of this thesis as the LBA covers the period 1600-1050 B.C. It is beyond the scope of this thesis to resolve this dating issue and I have taken the Aegeans portrayed as representatives of Mycenaean envoys or traders. This is a much debated topic among scholars who have proposed dates ranging from the Theran eruption 1650B.C. down to ca. 1450 B.C. For further discussions on this debate see Foster and Bichler 2003b: 431-440, Kantor 1947: 33-38, 48-49, 74, Manning *et al* 2001: 2532-2535, Merrillees 1972: 281-294, and Wachsmann 1987: 105-108.
[488] Rehak 1996: 35-41. Rehak gives additional supporting iconographic evidence that simple wrap-around kilts were worn in the Aegean, and were of a similar design to Egyptian examples (Figure 4.17, 1 and 3).

4.18).[489] Levantine textile garments excavated in 'The Cave of the Warrior' in the Judean desert are thought to be a kilt and sash. They were carbon dated to 2925 ± 50 B.C. (uncalibrated).[490] The total area of cloth used to make them was 1.57 $m^2$, of which 1.23 $m^2$ was the kilt and 0.34 $m^2$ was the sash. This compares well with an Egyptian example (kilt only) of 1.03 $m^2$.[491]

Sash kilts were common in the Eighteenth Dynasty New Kingdom Egypt as shown in the tombs paintings of Ramose and Huy (Figure 4.19). Only one sash kilt has been found to date, excavated at el-Qurneh.[492] A possible example of cross-cultural contact influencing design is the range of loincloths found in the tomb of Kha at Deir el-Medina. The upper edges of the loincloths are cut in a curved shape similar to the flounced skirt described above, which ensures a close fit at the waist (Figure 4.20).[493] Although breechcloths from the Aegean region do differ from the Egyptian loincloths, the area of cloth used to produce them, 0.42 $m^2$, was close to that required to make an Egyptian loincloth; 0.45 $m^2$.[494]

**The evidence for female dress**

A common garment found across the Eastern Mediterranean is the flounced skirt with tiers of multicoloured stripes or fringes.[495] The dress design shown in Figure 4.21 comprises a skirt made from a rectangular cloth with a variable number of multicoloured rectangular strips of cloth attached to the kilt. The basic design spread across the Eastern Mediterranean, as demonstrated from a large number of seals, wall frescoes, gold foil indentations, jar decoration, faiences, and Egyptian tomb paintings found across Mesopotamia, Aegean, and Eastern Mediterranean.[496] The flounced

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[489] Houston 1954: 115-116, Figure 116.
[490] Schick 1998c: 6, 21.
[491] For areas of cloth measured from attested Egyptian garments see dimensions in Report 4.1a in CLOTHCALC.
[492] It is on display at the Metropolitan Museum of Art, acc. no. 36.3.176 (Vogelsang-Eastwood 1993: 64-68). For tomb of Ramose see Davies and Peet 1941: Plate XXXII, tomb of Huy see Davies and Gardiner 1926: plates XIV-XV and statuette of Neb-nefer see Wild 1979: Plate 33.
[493] Schiaparelli 1927: 90, Figure 62.
[494] See Report 4.1e for my interpretation of the dimensions of breech cloths as drawn in Rehak 1996: 40, Figure 2.
[495] These flounced skirts originated in Mesopotamia during the reign of Sargon I of Akkad, 2334 B.C - ca. 2279 B.C. (Jones 2005: 707). Attested from the seal of the scribe Adad (British Museum 89 115).
[496] Jones 2005: 707-716 gives an extensive commentary on the flounced skirt covering its design, migration across the Near East and the Aegean, with a full bibliography and museum references. Also see Barber 1991: 318-319, plate 2 for additional information on the fabric design that used brightly

skirt and top have been reconstructed by Jones. The skirt and bodice require areas of 2.02 $m^2$ and the bodice 0.42 $m^2$, giving a total cloth requirement of 2.44 $m^2$.[497] This compares favourably with Vogelsang-Eastwood's measurements of a typical Egyptian long skirt of 2.4 $m^2$.[498]

Jones' analysis of the frescoes of the veiled dancer from Xesta, Thera dating to LC IA, and a banqueter from the Camp stool fresco, Knossos (LM II-IIIa) enabled her to reconstruct the Aegean v-neck dress and the straight long tunic dress (Figures 4.22-4.24).[499] The later had the option of a frilled over-mantle. The areas of the two dresses were 2.91 and 2.75 $m^2$ respectively. The area of the over-mantle was 3.92 $m^2$ resulting in an extraordinary area of cloth needed to make a combined tunic dress and mantle, of 6.67 $m^2$.[500] This amount of cloth could surely only be available to the top echelons of female Aegean élite. The largest complex wrap-around Egyptian wrap-around dress estimated by Vogelsang-Eastwood from tomb paintings was 4 $m^2$.[501]

## Conclusions

From the evidence above it is reasonable to conclude that there was a degree of commonality in basic garment designs across the LBA Eastern Mediterranean. Details of design and decoration varied but the experimental archaeology replicating the garments from the Aegean, Levant, and Egypt suggests that the areas of cloth required to make them were comparable.[502] On the balance of evidence, I shall use the Egyptian dimensions for garments as representative for the whole Eastern Mediterranean. This is not surprising for three reasons; outside of the high élite the

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coloured and complex patterns. Egyptian tomb paintings from the tombs of Rekhmire, Nebamun, and Horemheb covering a period from ca. 1450 B.C. – 1304 B.C. show captured Syrian women with flounced skirts.

[497] Note Jones 2005: Plate CLXXIX provides pattern for skirt only. The dimensions and area required for bodice is based on the recreation by Lillethun and Barber 2003: 463-475 of the bodice of the Young Saffron Gatherer (Doumas 1992: 40-41, plate 9). For details of dimensions used to analyse area of cloth required see Report 4.1d in CLOTHCALC.

[498] Vogelsang-Eastwood 1993: 181.

[499] Jones 2003: 441-450, plates LXXXVI and LXXXVIII.

[500] This area could be even greater as Jones poses the possibility that the stripes on the mantle could have been additional pieces. For the analysis Egyptian and Aegean dresses see Reports 4.1b in CLOTHCALC.

[501] Vogelsang-Eastwood 1993: 106-111, 181. Examples of the depictions of complex wrap-around dresses can be found in the tomb of Huy (Davies and Gardiner 1926: Plate XII) and tomb of Merya (Davies 1903: Plate XIII)

[502] See earlier discussions and citations of Jones and Vogelsang-Eastwood.

high cost of cloth would tend to optimise area of cloth per garment; the work patterns across all East Mediterranean culture would be ergonomically similar requiring similar garment designs, and Jones' work in particular demonstrates that increased contact in the LBA encouraged cross-cultural awareness of garment design.[503] While cultural factors do influence garment design, ethnographic evidence from rural communities shows that different societies wore similar garments to suit climate and work activity. The design adage that "form follows function" seems as applicable to clothes from ancient agricultural economies as it does to modern industrial design.[504]

The evidence above confirms kilts and tunic from others areas of the Eastern Mediterranean were similar in design to that of Egypt. It is however beyond the scope of this thesis to try and apply the methodology used by Vogelsang-Eastwood on Egyptian dress to the Aegean and Mesopotamia.[505] For simplicity this thesis assumes Egypt will be representative of other regions because they had similar hierarchical socio-economic profiles and the LBA had widespread contact between regions that encouraged some commonality in basic designs. Indeed it would be surprising if regions in Eastern Mediterranean, having such commonality in terms of climate and social conditions, did not find common design solutions to common needs.

**Area of cloth required to make LBA garments**

Reports 4.1a-4.1g in CLOTHCALC shows all the references and dimensions of garments that have been measured from extant garments or recreated garment patterns.[506] From these dimensions, the areas of cloth required to make them have been calculated. Allowances were made for gender by reducing the area for adult females by multiplying the male unit area by the factor 0.92 and for infants aged 0-3

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[503] Jones 1998, Jones 2000: 36-41, Jones 2003: 441-450 and Jones 2005: 707-720.

[504] Greenough 1969: XXI, 148 first introduced the term to describe works of art, particularly classical sculpture. It is now a basic tenant of modern industrial design where optimisation of cost and performance is at a premium.

[505] Vogelsang-Eastwood 1993.

[506] Patterns are given in Hall 1958: 235-245, Vogelsang-Eastwood 1992a and Johnstone 2007. Petrie Museum of Egyptian Archaeology The calculated unit areas include allowance for hemming the garments. Where a number of garments have survived and measurements taken, the average calculated area is employed.

and 4-9 by the factors 0.56 and 0.7 respectively.[507] Report 4.1b in CLOTHCALC is a matrix of the unit area of cloth collated by garment type and socio-economic group. A matrix of the number of garments owned collated by garment type and/or socio-economic group is given in Report 4.3a in CLOTHCALC. The rationale for this matrix is outlined below in Section 4.4.3 below. Multiplying the two matrices together will give the total area of cloth required to clothe 100,000 people, discussed in Section 4.4.4 below.

## 4.4.3 The number of garments owned

Having defined common garment designs representative of the LBA Eastern Mediterranean, this section will estimate the number of garments by type and/or socio-economic group. Three key sources of evidence were used to quantify these numbers.

1. The archaeological evidence from intact tombs has been used for the élite wardrobe.
2. The typology study of Volgelsang-Eastwood and the textual study of Janssen have been used for the lower élite and skilled craftsmen.[508]
3. For the farm workers, Egyptian tomb depictions from the agriculture scenes have been used.

### The archaeological evidence from intact tombs

Drawing parallels between the goods placed in Egyptian tombs and how representative they were of daily life is open to debate. Only a very small percentage of élite tombs have survived with an intact burial assemblage and of these only the 18th Dynasty tomb of Kha or Merit has an almost complete wardrobe of garments.[509]

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[507] Killen's study of Egyptian beds suggests that the average height of adult males was 1.71 m (Killen 2003: 33). This is approximately 4-5 cms less than the average modern European male. Using UK government statistics the average heights for men and women are 1.753 m and 1.614 m respectively. Average heights of a child aged three and seven are 0.98 and 1.22 m respectively. It is considered that modern height statistics are close enough to those of antiquity so they have been used in this study, as shown in Report 4.1c.

[508] Vogelsang-Eastwood 1993, Vogelsang-Eastwood 1994, Janssen 1975a: 249-292 and Janssen 1995: 383-394.

[509] This may well be due to the humid conditions within tombs prone to flash floods at irregular intervals. This is a marked contrast to textile fragments found in settlement contexts in more arid conditions such as the Amarna Workmans Village (Kemp and Vogelsang-Eastwood 2001: 165-245). Other 18th Dynasty New Kingdom tombs with significant caches of tomb goods are those of Sennefer and Nefertiry (Bruyère 1929: 40-73); Stetau, Taat and Bakiset (Bruyère 1937b: 95-107), Madja (Bruyère 1937b: 100), Nubiyiti (Bruyère 1937b: 183-188), Satre ((Bruyère 1937b: 191). Only one 19th Dynasty tomb exists with a significant tomb assemblage, that of Sennedjem which demonstrates the

In the New Kingdom in particular, the choice of goods reflected more about how the deceased wished to be seen in the afterlife rather than an exact replication of the deceased's life experiences. However in the 18th Dynasty in particular there was some overlap, which can be inferred as they predominantly used objects from the world of the living.[510] The wardrobe of the 18th Dynasty tomb of Kha and Merit from Deir el-Medina does seem representative of how the high élite, particularly males, were portrayed in tomb depictions. As a result this evidence has been chosen as the main source to estimate the number of garments typically owned by the high élite (socio-economic group 1).

Kha belonged to a social group that had considerable social interaction with the highest levels of élite society but were not nobility themselves.[511] Of particular importance to this section are the number and variety of garments found intact in the tomb. Kha's wardrobe consisted of 50 triangular loin cloths, 26 knee-length garments that wrapped around the hips and 17 sleeveless tunics (Figure 4.25).[512] In addition, there were at least 22 fringed pieces of linen that Schiaparelli called table cloths and bolts of fringed cloth (Figures 4.26-4.27).[513]

It is not obvious from the total garment assemblage found in Kha's tomb how they were divided between him and his wife Merit. Many of the garments examined have the name of Kha printed or embroidered on them (Figure 4.28).[514] Merit obviously had clothes in her own right and some of the pieces of linen discussed above

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funerary nature of a tomb assemblage rather than daily goods (Bruyère 1926: 190-192). See Meskell 1999: 176-212 for a study of these tombs from a perspective on what can be deduced about the individuality of the tomb owners through an analysis of their choice of tomb goods.

[510] Meskell 1998: 364. The responsibility for ensuring that personal wishes were met was that of the eldest surviving son of the deceased who acted as the *sem* priest (Meskell 1998: 366.).

[511] Kha's burial assemblage shows he was awarded prestigious gifts by three Pharaohs. His titles show that Kha was Chief in the Great Palace and Director of Public works in the Royal administration supporting Amenhotep III. The most prestigious gift was the gold "necklace of valour" given by Amenhotep II. This was discovered from a X-ray analysis of the mummy showing the necklace around the neck under several levels of bandages (Meskell 1998: 372), He also received a measuring rod one cubit long covered in gold leaf from Amenhotep II (Schiaparelli 1927: 169-171. Tuthmosis IV gave him a writing case bearing the cartouche of the King (Schiaparelli 1927: 81, Figure 48). Amenhotep III gave him an electrum cup (Schiaparelli 1927: 172, Figure 157).

[512] Schiaparelli 1927: 91-93, Figures 63-69.

[513] Schiaparelli 1927: 98-100, Figure 66 and 70. They are more likely however to be bolts of cloth it is more likely to have been used for a wide range of uses such as blankets, wrap-around cloaks, kilts and skirts or shawls.

[514] Source Schiaparelli 1927: 98, Figure 71. Hall 1986: 37 suggests that some of the loin cloths, despite the laundry marks of Kha's name could have been shared with Merit.

probably belonged to Merit. A folded dressing gown with additional side sections of fringed linen with Merit's own ink laundry mark was found in her personal basket (Figure 4.29). Warm blankets and folded sheets were placed on her bed (Figure 4.30).[515] Most of the loin cloths in Kha's tomb had laundry marks showing that they had been worn at least once and were not produced just for mortuary purposes.[516] Meskell and Tyson Smith have clearly demonstrated that while the goods found in intact Egyptian tombs favour the man in both quantitative and qualitative terms, the wife also owned property in her own right. However, Merit's boxes are made of poor quality wood, badly finished and poorly painted.[517] Meskell has valued the tomb goods in relation to the copper *deben*. The total value of all the tomb goods is 3,919 *deben* to Kha and 787 *deben* to Merit (approximate ratio 5:1).[518] As commented above, this is probably distorted in Kha's favour due to the uncertainty about how many of the garments belonged to Merit. Subtracting the value of clothes from Kha's share (3,919-1,395 = 2,524 *deben*) and the value of linen and bed linen from Merit's share (787-150= 637 *deben*) gives a normalised prorated lower ratio of 4:1.[519] On the basis of decorum and day-to-day practicality, there will be a minimum number of clothes that Merit would require in public life. The wife of the high élite reflects the status of the husband and she is shown in tomb depictions at public gatherings; attending her husband's award ceremonies from the Pharaoh, banquet scenes and in the commonly held female role as 'Chantress of Amun' in temple rituals.[520] This thesis has allocated the wife of a high élite official a ratio 2:1 in the husband's favour which allows for sufficient cloth to make garments reflecting the status of the husband in public ceremonies.[521]

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515 Hall 1986: 38 and Schiaparelli 1927: 105-106, Figures 78, 80; 129, Figure 105.

516 Hall 1986: 35, 37. In particularly Hall 1986: 35, Figure 24.

517 Kha had 211 items attributed to him, compared to 41 belonging to Merit. Meskell 1998: 373. For further discussion on material inequalities between gender and class see Meskell 1994: 193-216; Meskell 1999: 136-215 and Tyson Smith 1992: 193-231.

518 Meskell 1998: 374, Table 1. Meskell has used the *deben* prices as developed by Janssen 1975a: 510-538.

519 For the full analysis in CLOTHCALC see Report 4.3c.

520 The importance of appearance in elite society is clearly reflected in tomb depictions of wives who are shown youthful, with no indications that they had borne many children (Robins 1993: 181-182). As for the status of women, and their titles and public activities, see Robins 1993: 114-117. For the role of women in temple ritual see Robins 1993: 142-148.

521 For the full analysis in CLOTHCALC see Report 4.3e.

One ostracon from Deir el Medina states that the householder had three cloaks, 10 kilts and 15 loincloths. His wife had two loin cloths, one tunic and one sash, a pair of sleeves and 2 sheets.[522] This list must have been from a wealthy member of the élite, but not as well positioned as Kha and Merit. It may well be an example of the wardrobe of a senior official in socio-economic 2.

## Wardrobe of socio-economic group 3

The next group to study are those from socio-economic group 3 which incorporates professions such as scribes, architects, engineers, and low-medium ranked priests (hereafter called the professional class). Vogelsang-Eastwood's comprehensive study of Egyptian clothing has enabled her to make an assessment of the wardrobe of the lower professional class of the élite to which I have allocated the wardrobe of a member of socio-economic group 3. Her analysis has taken all the available evidence from tomb depictions, tomb goods and textual evidence. Her findings suggest that a male member of this group in the New Kingdom would own; two loincloths, two aprons, two knee-length kilts, one long kilt, two sash kilt, two long bag-tunics, two short bag-tunics, and two cloaks. The wife would own five loincloths, two wrap-around skirts, one simple wrap-around dress, two complex wrap-around dresses, six sashes and two cloaks.[523] These lists clearly demonstrate the hierarchical nature even within the élite when they are compared to those found in the tomb of Kha and Merit. Vogelsang-Eastwood's lists do not include kerchiefs, shawls and sashes which are attested in tomb paintings and texts, for which she herself gives references.[524]

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[522] Hall 1986: 62. Note that women wore the same design of loincloths as men.

[523] Vogelsang-Eastwood 1993: 182 has given these lists of garments in terms of area of cloth. The number of items have been converted to equivalent garments, rounding to the nearest whole garment , by dividing by the area to make each garment as published in her book 'Patterns for Ancient Egyptian Clothing (Vogelsang-Eastwood 1992a). She has used the measurements of surviving Egyptian garments from Egyptian, North American and European museums to assess the method of construction of the garments and the area of cloth used in manufacture. She reproduced the garments and this experimental archaeology also helps our understanding of how the more complex kilts, tunics, cloaks and dresses were wrapped around the body to create the desired effect.

[524] For this analysis I have added to her list two kerchiefs for the male, and one for kerchief for the woman, one medium/long shawl for the male and one for the woman, two short shawls for the male and two for the woman, and 2 sashes for the male and one for the woman. For elite kerchiefs see Winlock 1942: 10 and Vogelsang-Eastwood 1992b: 46. For farm workers kerchiefs see Vogelsang-Eastwood 1992b: 45. For elite shawls see Brunton 1940: 522, 527, Schiaparelli 1927: 93, Vogelsang-Eastwood 1992b: 37, and Vogelsang-Eastwood 1993: 101,181. For sashes see Janssen 1975a: 286, Vogelsang-Eastwood 1992b: 21 and Vogelsang-Eastwood 1993: 73-76.

## Wardrobe of socio-economic group 4

Many ostraca from Deir el-Medina have been found to contain laundry lists. They attest to workers having loincloths, sanitary cloths, tunics, bag-tunics, draped dresses, sleeves, kerchiefs for the head as protection from the sun, and sashes worn around the waist and crosswise around the body to absorb sweat.[525] It is clear that clothes were recycled and had been previously been worn extensively in daily life.[526]

## Wardrobe for socio-economic group 5

The members of this group, predominantly farm workers and labourers, are the most difficult to define as there is no archaeological evidence that can be said to be representative of this group. From the limited evidence above it is clear that a hierarchical pattern would continue in this group and their requirements would be limited to the bare practical minimum. Tomb scenes show workers in the fields and a certain pattern can be deduced. In the fields, some workers are shown wearing kerchiefs, presumably as a protection from the hot sun (Figure 4.31). Loin cloths, kilts and short skirts with sashes are commonly represented (Figures 4.32-4.33). Wrap-around cloaks made from coarse cloth were probably worn as a protection from wind-blown dust as much as for warmth at night (Figure 4.34).[527] The rationale taken for this thesis in terms of numbers and designs of garments owned is to assume a minimum of one of each type of garment for this group. This would provide the minimum demand for cloth, but it should be remembered that if this is understated it would have a significant impact on the surplus, as the population of this socio-economic group 5 was so large.

## Total numbers of garments owned

To achieve a sensible balance of garments across all socio-economic groups some interpolation is required to fill the gaps. Report 4.3a is the resulting matrix of garments owned and collated by socio-economic group, sex, age, and garment type. The total number of garments owned is 574,637 per 100,000 population. Tables 4.3-

[525] Janssen 1995: 391-392.
[526] Petrie found that garments in funerary contexts at Deshasheh were worn and frequently darned (Hall 1958: 239 citing Petrie 1898: 47-50 first-hand account of his excavation).
[527] Kemp and Vogelsang-Eastwood 2001: 237.

4.4 below collate the number of garments owned by socio-economic group, male/female and children, and garment type.

| Socio-economic groups | 1. High elite | 2. Senior officials | 3. Profes-sionals | 4. Crafts-men | 5. Farm workers | Total |
|---|---|---|---|---|---|---|
| Male 10+ | 7,222 | 6,700 | 26,040 | 53,136 | 231,192 | 324,290 |
| Female 10+ | 3,082 | 3,100 | 14,280 | 43,173 | 173,394 | 237,029 |
| Child 0-9 | 966 | 1,326 | 4,270 | 6,756 | - | 13,318 |
| **Total** | 11,270 | 11,126 | 44,590 | 103,065 | 404,586 | **574,637** |

**Table 4.3: Number of garments worn collated by socio-economic group and age**

| Garment types | 1. High elite | 2. Senior officials | 3. Profes-sionals | 4. Crafts-men | 5. Farm workers | Total |
|---|---|---|---|---|---|---|
| Loin Cloths | 2,461 | 1,353 | 5,467 | 13,284 | 57,798 | 80,363 |
| Kilts | 1,242 | 1,000 | 5,880 | 9,963 | 28,899 | 46,984 |
| bag-tunics | 920 | 1,153 | 4,627 | 6,642 | 57,798 | 71,140 |
| Sashes | 874 | 651 | 2,520 | 6,642 | 57,798 | 68,485 |
| Aprons | 644 | 753 | 2,107 | 3,321 | - | 6,825 |
| Shawls | 1,426 | 1,706 | 5,894 | 13,284 | - | 22,310 |
| Cloaks | 943 | 951 | 3,787 | 11,652 | 57,798 | 75,131 |
| Skirts and dresses | 1,104 | 1,204 | 4,214 | 18,294 | 28,899 | 53,715 |
| Kerchiefs | 552 | 902 | 2,947 | 8,331 | 57,798 | 70,530 |
| Blankets | 1,104 | 1,453 | 7,147 | 11,652 | 57,798 | 79,154 |
| **Total** | **11,270** | **11,126** | **44,590** | **103,065** | **404,586** | **574,637** |

**Table 4.4: Number of garments worn, collated by socio-economic group and garment type**

### 4.4.4 The total area of cloth required to clothe 100,000 people.

The total area of cloth required to clothe 100,000 people is calculated simply by the multiplication of the matrix of the unit areas of each type (Report 4.1a) by the number of garments owned by each socio-economic group (Report 4.3a). The total area of cloth required to maintain the garments across all socio-economic groups is 577,705 m$^2$. A summary of the results are given in the table below.

| Area of cloth m$^2$ required/100,000 population | | | | | | |
|---|---|---|---|---|---|---|
| Garment types | 1. High elite | 2. Senior officials | 3. Profes-sionals | 4. Crafts-men | 5. Farm workers | Total |
| Loin Cloths | 1,576 | 1,353 | 5,467 | 13,284 | 57,798 | 79,478 |
| Kilts | 2,632 | 1,000 | 5,880 | 9,963 | 28,899 | 48,374 |
| Bag-tunics | 1,788 | 1,153 | 4,627 | 6,642 | 57,798 | 72,008 |
| Sashes | 593 | 651 | 2,520 | 6,642 | 57,798 | 68,204 |
| Aprons | 318 | 753 | 2,107 | 3,321 | - | 6,499 |
| Shawls | 2,153 | 1,706 | 5,894 | 13,284 | - | 23,037 |
| Cloaks | 2,009 | 951 | 3,787 | 11,652 | 57,798 | 76,197 |
| Skirts and dresses | 1,104 | 1,204 | 4,214 | 18,294 | 28,899 | 53,715 |
| Kerchiefs | 302 | 902 | 2,947 | 8,331 | 57,798 | 70,280 |
| Blankets | 1,863 | 1,453 | 7,147 | 11,652 | 57,798 | 79,913 |
| **Total** | **14,338** | **11,126** | **44,590** | **103,065** | **404,586** | **577,705** |

**Table 4.5: Area of cloth (m$^2$) required to clothe 100,000 people in Egypt**

The climate of the north-eastern Mediterranean is much harsher than Egypt in winter and less hot in summer. The average temperature of Nicosia in January for example is 10.6 °C compared with 16.1°C at Luxor. This temperature difference can only partially be compensated for with the use of wool compared with the Egyptian use of flax. To reflect this in the demand for cloth, that amount has been modified by increasing the demand for cloaks by 20% and blankets by 20% but reducing the number of kerchiefs used as a protection from sunstroke by 30%. The resulting total area of cloth required to maintain the garments required across all socio-economic groups is 587,843 $m^2$. A summary the total area of cloth collated by socio-economic group and garment type is given in the table below.

| Area of cloth $m^2$ required/100,000 population | | | | | | |
|---|---|---|---|---|---|---|
| **Garment types** | **1. High elite** | **2. Senior officials** | **3. Profes-sionals** | **4. Crafts-men** | **5. Farm workers** | **Total** |
| Loin Cloths | 1,576 | 1,353 | 5,467 | 13,284 | 57,798 | 79,478 |
| Kilts | 2,632 | 1,000 | 5,880 | 9,963 | 28,899 | 48,374 |
| Bag-tunics | 1,788 | 1,153 | 4,627 | 6,642 | 57,798 | 72,008 |
| Sashes | 593 | 651 | 2,520 | 6,642 | 57,798 | 68,204 |
| Aprons | 318 | 753 | 2,107 | 3,321 | - | 6,499 |
| Shawls | 2,153 | 1,706 | 5,894 | 13,284 | - | 23,037 |
| Cloaks | 2,411 | 1,141 | 4,544 | 13,982 | 69,358 | 91,436 |
| Skirts and dresses | 1,104 | 1,204 | 4,214 | 18,294 | 28,899 | 53,715 |
| Kerchiefs | 211 | 631 | 2,063 | 5,832 | 40,459 | 49,196 |
| Blankets | 2,236 | 1,744 | 8,576 | 13,982 | 69,358 | 95,896 |
| **Total** | **15,022** | **11,336** | **45,892** | **105,226** | **410,367** | **587,843** |

**Table 4.6. Area of cloth ($m^2$) required to clothe 100,000 people in North-East Mediterranean**

The tables above show the total area of cloth that would be required to replace the wardrobe entirely at one point in time. In reality the garments were replaced on a regular basis due to wear-and-tear. The annual demand for cloth needed to replace worn-out garments is therefore lower and this will be discussed in Section 4.4.5 following.

## 4.4.5 Annual cloth requirement

Section 4.4.3 estimated that 100,000 people would own 574,637 garments in total at any given time. This equates to an area of cloth of 577,705 $m^2$ and 587,843 $m^2$ for Egypt and North East Mediterranean respectively.[528] This section evaluates the area of cloth needed annually to meet and maintain these statistics. This evaluation takes four factors into account:

[528] Reflecting differences in climate as discussed in Section 4.4.4.

1. Minimum number of garments needed to carry out the duties of the individual.
2. Number of garments acquired in addition to these as conspicuous consumption.
3. Wear-and-tear of garments in use.
4. The assumption that if individuals had reached an age of 11, their life expectancy would be 30 years.[529]

This evaluation will provide an amortised annual requirement for cloth necessary to supply each socio-economic group with their estimated clothing needs. As discussed in Section 4.4.4 the accumulation rate differs for each socio-economic group. It has been assumed, due to the cost of clothes, that the farm workers and craftsmen (socio-economic groups 4-5) owned the minimum number of garments to carry out their manual duties. At the other end of the social scale the high élite (socio-economic group 1) had more clothes than would be expected to carry out their duties. For this group a significant proportion of garments accumulated because they would have been worn only occasionally as reflected in the practice of LBA élite society reinforcing status through conspicuous consumption.[530]

Wear-and-tear of textiles depended on the number of days worn, the type of work carried out in them, and the gradual deterioration through laundering. The Egyptians used bleach, probably natron, to whiten flax cloth and combined with the destructive power of ultra-violet sun rays, this had the tendency to lighten and weaken the cloth fibres.[531] It has been assumed that the clothes of the farm workers would survive the shortest length of time because of their manual labour and fewer clothes to spread out the wear, and this has been estimated as 3.5 years per garment.[532] For the élite in socio-economic groups 1-3 the reverse is the case, with clothes surplus to

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[529] See Report 3.6a using the Coale-Demeny South level 3 demographic model as discussed earlier in Section 3.2.3.
[530] This is clear from the garments found in the tomb of Kha and Merit where there is a mix of almost pristine clothes and those that have been clearly worn, laundered and pressed (Schiaparelli 1927: 92-98).
[531] Thirteen linen samples of textiles from the Workmens Village in Amarna of which four unbleached samples showed considerable evidence of wear, seven bleached samples showed considerable evidence of wear, and only two showed little sign of wear. These samples were examined by the Textile Department at the University of Manchester (Kemp and Vogelsang-Eastwood 2001: 282-283).
[532] This is an estimate based on reasonableness for the harsh conditions faced by manual workers. If all clothes across all socio-economic groups wore out that this high rate of 3.5 years per garment then the total workers CLOTHCALC shows that the total number of cloth workers would increase for Egypt and Cyprus by 7.5% and 5.6% respectively.

requirement requiring replacement every 7.5 years. For lower professional classes, socio-economic group 3, a mid point of replacement every 5.5 years has been chosen.

## The amortised annual rate of cloth production

The loin cloth has been chosen to explain how the area of cloth is calculated for each socio-economic grouping across all garment types.[533] The amortised rate ($m^2$/yr) is the annual area of cloth required to be made each year to ensure that the individual has the number of garments as given in Report 4.3a. For the full analysis of theses rates three additional worksheets should be referred to W&T 3.5 yrs, W&T 5.5 yrs, and W&T 7.5 yrs. A summary of these analyses is given in Report 4.4b.

### Socio-economic group 4-5

The simplest case to evaluate is that of socio-economic groups 4-5. For these groups it is reasonable to assume that the number of garments owned was the minimum required to carry out their arduous duties. Taking as an example of how the area of cloth is calculated for the loin cloth, the males of this group have been assumed to own one loincloth per person, and as they worked in harsh working conditions each loincloth has been assumed to wear out every 3.5 years. At this rate of replacement, and assuming a working life of 30 years, he would require 10 loincloths over this period of time.[534] The amortised rate per annum would therefore be $10 \div 30 = 0.33$ loincloths per annum.[535] The total amortised annual rate of cloth for all the males in this group equals; the number of male farm workers × unit area of long bag-tunic × amortised rate = $28{,}899 \times 0.45 \times 0.33 = 4{,}292$ $m^2$ of cloth. A similar calculation for all males, females, and children is used for other items of their apparel.

### Socio-economic group 3

Socio-economic group 3, who were better clothed than farm workers and skilled craftsmen, probably did not buy garments for conspicuous consumption purposes. To reflect a more sedentary life, and a larger wardrobe, giving them the option of having

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533 For the full evaluation of cloth see Module 5 in CLOTHCALC.

534 See Report 4.4d in worksheet W&T 3.5 yrs shows the Boolean methodology used in the analysis. For numbers of garments collated by socio-economic group and garment type see Report 4.3a.

535 This means a manual workers loincloth would be replaced every 3 years.

a change of clothes to reduce garment deterioration, the rate of replacement due to wear-and-tear has been increased to 5.5 years. The number of loincloths allocated to this socio-economic group is 3.[536] At this rate of replacement and assuming a working life of 30 years, an individual would require 12 loincloths over this period of time. The resulting amortised annual wear-and-tear rate is therefore 0.4 loincloths per annum.[537]

**Socio-economic group 1**

For the high élite socio-economic groups 1-2, wear-and-tear would have been even less. As stated above, a significant number of garments would have been accumulated over and above those required for their daily duties. For these groups it is assumed that their garments only required replacement every 7.5 years. The assumed number of loincloths allocated to this socio-economic group on the basis of the evidence of Kha is 35.[538] In this case the total number of loincloths required to ensure the male deceased ended up with 35 loincloths would be 94.[539] This results in a combined amortised accumulation and wear-and-tear rate over 30 years was equal to $94 \div 30 = 3.13$ loincloths per annum. The amortised annual rate of cloth required to be made each year equals the number of male high élite × unit area of a loincloth × combined amortised rate= $46 \times 0.45 \times 3.13 = 65$ m$^2$ of cloth per annum. As before, similar calculations are carried out for all the items of clothing.

## 4.4.6 Annual cloth requirement

### Correlation by garment type and social economic group

Tables 4.7-4.8 below show the area of cloth required to be made each year to ensure sufficient cloth to clothe a sample 100,000 population for Egypt and the North East Mediterranean (Reports 4.5c-4.5d in CLOTHCALC). Table 4.8 reflects the climate differences between the two areas as discussed earlier in section 4.4.4 (see again Figure 3.2).

[536] See again Report 4.3a.
[537] See Report 4.4c in Worksheet W&T 5.5 yrs.
[538] See Report 4.3a.
[539] See Report 4.4f in Worksheet W&T 7.5 yrs.

| Garment types | 1. High elite | 2. Senior officials | 3. Profes-sionals | 4. Crafts-men | 5. Farm workers | Total |
|---|---|---|---|---|---|---|
| Loin Cloths | 96 | 55 | 316 | 1,514 | 8,202 | 10,183 |
| Kilts | 234 | 211 | 1,203 | 4,608 | 7,153 | 13,409 |
| Bag-tunics | 170 | 230 | 1,293 | 4,417 | 38,433 | 44,543 |
| Sashes | 30 | 28 | 168 | 822 | 7,152 | 8,200 |
| Aprons | 22 | 30 | 139 | 449 | - | 640 |
| Shawls | 226 | 308 | 1,745 | 7,540 | - | 9,819 |
| Cloaks | 227 | 243 | 1,556 | 7,713 | 30,804 | 40,543 |
| Skirts and dresses | 283 | 361 | 2,142 | 14,324 | 7,439 | 24,549 |
| Kerchiefs | 16 | 30 | 157 | 1,896 | 16,498 | 18,597 |
| Blankets | 198 | 279 | 1,956 | 6,557 | 39,100 | 48,090 |
| **Total** | **1,502** | **1,775** | **10,675** | **49,840** | **154,781** | **218,573** |

**Table 4.7: Amortised annual area m$^2$ of cloth required for domestic clothing for 100,000 people in Egypt.**

| Garment types | 1. High elite | 2. Senior officials | 3. Profes-sionals | 4. Crafts-men | 5. Farm workers | Total |
|---|---|---|---|---|---|---|
| Loin Cloths | 96 | 55 | 316 | 1,514 | 8,202 | 10,183 |
| Kilts | 234 | 211 | 1,203 | 4,608 | 7,153 | 13,409 |
| Bag-tunics | 170 | 230 | 1,293 | 4,417 | 38,433 | 44,543 |
| Sashes | 30 | 28 | 168 | 822 | 7,152 | 8,200 |
| Aprons | 22 | 30 | 139 | 449 | - | 640 |
| Shawls | 226 | 308 | 1,745 | 7,540 | - | 9,819 |
| Cloaks | 272 | 292 | 1,867 | 9,256 | 36,965 | 48,652 |
| Skirts and dresses | 283 | 361 | 2,142 | 14,324 | 7,439 | 24,549 |
| Kerchiefs | 11 | 21 | 110 | 1,327 | 11,549 | 13,018 |
| Blankets | 238 | 335 | 2,347 | 7,868 | 46,920 | 57,708 |
| **Total** | **1,582** | **1,871** | **11,330** | **52,125** | **163,813** | **230,721** |

**Table 4.8: Amortised annual area of cloth m$^2$ required for domestic clothing for 100,000 people in the North East Mediterranean**

# 4.5 Production of linen cloth in the LBA

The next three Sections 4.5-4.7 will concentrate on the processes and manpower resources required for the production of flax fibre for linen cloth. As an introduction to this new topic, this section starts with an overview of the development of the use of flax in the Eastern Mediterranean from the Neolithic period to the LBA. This is followed by the physical properties of flax. Section 4.6 will analyse the agricultural process involved in growing flax with its associated manpower. Section 4.7 will investigate the processes used in the LBA to produce flax fibre that was suitable for spinning. Section 4.8 will compare the manpower required for the husbandry of sheep and the preparation production of wool fibre and compare it to that required to make an equivalent weight of flax fibre as identified in Sections 4.5-4.7.

## 4.5.1 The development of flax production

The most common type of flax was *Linum usitatissimum* which grew 0.8 and 1 m high with green spear-shaped leaves tapering towards the ends, and having blue flowers.[540] Flax production for textiles and linseed oil production has a long history in the Eastern Mediterranean and its development is plotted in Figure 4.35.[541] Linen textile remnants have been found in the Judean Nahal Hemar cave dated to Seventh Millennium B.C.[542] In Mesopotamia flax seeds have been found at Tell es-Sawwan and Choga Mami in ca. 6000-5500 B.C. contexts, and at Khafajah in Old Babylonian contexts ca. 1800-1600 B.C.[543] Significant flax production is known to have taken place in LBA Mycenaean Mainland Greece, as attested in the Pylos Na, Ng and Nn tablets.[544] Electron microscopic examination and chemical tests of charred textile remnants from Çatal Hüyük show that flax textiles were worn in Anatolia as early as the Sixth Millennium.[545] Wild flax was not indigenous to Egypt and the earliest

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[540] The progenitor of cultivated flax *Linum usitatissimum* was probably *Linum bienne* which grew as a perennial plant along the Mediterranean coast and the foothills of Iran and Iraq-Kurdistan (Helbaek 1959: 105-107 and Helbaek 1960: 105-107).

[541] The archaeological record indicates that the use of flax preceded that of wool, evidenced by flax seed which have been found in pre-Neolithic pots from Syria and in the Zagros Mountains in the western part of Iran dated to ca. 8000 B.C. (McCorriston *et al* 1997: 517-535, and Wild 2003a: 40). Flax was grown in the Levant from ca. 7000 B.C., either for textiles or oil (Zohary 1969: 144.).

[542] Schick 1998a: 38.

[543] Renfrew 1985: 63.

[544] Robkin 1979: 469-470 and Ventris and Chadwick 1973: 295, 468, 470-471.

[545] Ryder 1965: 175-176 and Burnham 1965: 169-174.

archaeo-botanical evidence comes from the largest Neolithic site Kom W in the Fayum of Lower Egypt.[546]

## 4.5.2 The physical properties of flax

The fibrous structure of the flax stem is the key to its success as a material suitable for spinning and weaving. Mesopotamian UR III records explicitly state that there were three quality grades of flax; "Heart of the flax" for the finest linen, "fibres for linen of third grade", and fourth grade "ordinary fibres."[547] Flax belongs to the family of plants whose fibres are contained in bast bundles (Figure 4.36).[548] These bast bundles are elongated cells which reinforce the flax stem against bending moments from the prevailing wind.[549] The advantage of flax over many other species of plants with bast bundles lies in its suitability for spinning. Each fibre of the plant is made up of thousands of fibrils that are arranged in a left handed spiral similar to the fibres in twisted thread. This helps the flax resist wear after it has been woven into cloth.[550]

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[546] Allgrove-McDowell 2003: 31.
[547] Jacobsen 1970: 222-223. This implies that there must have been a second grade that has not survived in the textual record.
[548] Kemp and Vogelsang-Eastwood 2001: 26, Figure 2.1.
[549] Flax consists of three main parts: a woody core with a hollow centre, the flax fibre itself and an outer cortex (bark). An analysis of these three components shows that only 12% by weight of the original harvested green flax remains as flax fibres suitable for linen. The remaining 88% was probably used, as today, for fodder and thatching. By convention in the linen industry the harvested product before processing is called green flax and will hereafter be used in this thesis. Published yield rates are fibre yield not green harvest yields. This thesis will use the same convention.
[550] Caldwell 1931: 4-5.

# 4.6 Cultivation of flax

The purpose of the next four sections is to quantify the manpower required to grow sufficient flax to support the annual production of 218,573 m$^2$ of cloth for Egypt, which provided the domestic clothing for a sample 100,000 population.[551] Section 4.6.1 provides an overview of the flax cultivation cycle so that the analysis of the required weight of flax, the area under cultivation and the manpower required to grow it, can be placed in context. Section 4.6.2 determines the weight of flax fibre required to make 218,573 m$^2$ of linen. Section 4.6.3 will calculate the land required growing the flax needed to make this area of cloth, and finally Section 4.6.4 will determine the manpower required to cultivate and harvest the flax.

## 4.6.1 The flax cultivation cycle

In Egypt linseed (seed of the flax) was sown by broadcast from late October to Mid-November and harvested in March-mid April.[552] In the Aegean, reflecting cooler climates, flax is sown in the period May to mid June and harvested in September.[553] Timing was important as the optimum time to harvest the flax is when the stems are half-ripe with fine fibres. Any delay causes the fibres to coarsen, making them unsuitable for spinning, although they still had economic value as a source to make ropes and matting.[554] For both Egypt and Mesopotamia, ropes were needed for the control of sailing boats and were vital to the success of the economy that depended on the effective flow of goods up and down the Nile, Tigris and Euphrates.

Flax requires prime land that readily drains, as it is particularly prone to waterlogging, but in the growing season it requires frequent watering.[555] Varro and Pliny recommended that the soil should be prepared by ploughing three times and sowing before the advent of winter.[556] In Egypt, sowing started in November, following the inundation.[557] The wall painting in the Middle Kingdom tomb of

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[551] Discussed and quantified in Section 4.4.5.
[552] Foaden and Fletcher 1910: 424-425.
[553] The Aegean dates reflect modern farming practices but the climate pattern probably dictated a similar time table.
[554] Allgrove-McDowell 2003: 32.
[555] Bradbury 1920: 22-28.
[556] Varro *r.r* 1.29 and Pliny *NH* 18.228-2.
[557] Vogelsang-Eastwood 2000: 270.

Urarna shows the ploughing and sowing cycle of flax, with a flock of sheep used to trample in the seed (Figure 4.37).[558] Flax germinates within 8-15 days and takes between 80-100 days before harvesting can start.[559] It is deliberately grown thickly to prevent the plant branching which is detrimental to producing long fibres and it is reasonable to assume the same practice was carried out in antiquity.[560]

Before the advent of herbicides, weeding was imperative when the plants reached a height of 0.08m. This prevented weeds from smothering the tender flax plants, taking away sunlight and robbing them of nutrients.[561] Weeds also contaminate the water during the retting process, which can damage the bast fibres.[562] Only young green leaves must be used for fine woven linen.[563] When the flax grew to approximately one metre it was harvested by pulling rather than cutting the stems to maximise the fibre yield (Figure 4.38).[564] Approximately 25-30 stalks were pulled at a time as root resistance prevented removal of larger quantities.[565]

## 4.6.2 Weight of flax fibre required

There is negligible loss in flax fibre material during the spinning process so it can be assumed that the weight of flax fibre required equals the weight of flax yarn to weave the cloth. Knowing the weight of yarn used to make 218,573 $m^2$ of cloth can be assumed therefore to be the weight of dry fibre that has to be produced in the fields. The weight of yarn can be calculated from the formula:

Total weight of yarn = area of cloth ($m^2$) × length of yarn required to make one square metre of cloth ($m/m^2$) ÷ length of yarn per unit weight (m/kg) [566]

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[558] Davies 1901: Plate XVI.
[559] Leadbeater *et al* 1976: 55.
[560] Leadbeater *et al* 1976: 55. MacAdams 1847: 13 notes the seed rate in Ireland in the 19th Century A.D. was 126 lbs/acre (141 kg/hectares) and the yield rate of flax seed (linseed) is 557 kg/hectares. This allows a significant surplus over that required to grow next years crop that can be used as a by-product to make linseed oil.
[561] MacAdams 1847: 14.
[562] McCorriston *et al* 1997: 522. Retting is a biological process that helps to break down the flax stem so that the fibres required to make the dry fibre can be easily removed (see later discussion in Section 4.7.1).
[563] Vogelsang-Eastwood 2000: 270.
[564] Vogelsang-Eastwood 2000: 270. Pliny, *Natural History* 5, 431, 19-3 states the harvesting of flax as "plucked up and tied together in little bundles each about the size of a handful".
[565] Allen 2002: 173, footnote 155 citing personal communication with E. Barber and V. Shaffer (Leffert's Homestead Children's Museum, New York.
[566] It can be seen that by cancelling units $m^2 \times m/m^2 \div m/kg$ leaves weight of yarn in kg.

For clarification, the area, length of yarn and weight of yarn per unit length will be referred to in this section as Factors 1-3. To further this section each of these factors will be considered in turn.

## Factor 1: Area of cloth required

The required 218,573 $m^2$ of cloth for Egypt and 230,721 $m^2$ for Cyprus has been distributed between their associated socio-economic groupings in the table below.[567] The socio-economic groups reflect the relative affluence of the socio-economic group and the degree of wear expected due to the daily activity of the wearer, 1-2 the least, 3-4 average, and farm workers socio-economic group 5 would exhibit the highest wear.

| Socio-economic groupings | Egypt Area of cloth $m^2$ | Cyprus Area of cloth $m^2$ |
|---|---|---|
| Socio-economic group 1 | 1,502 | 1,582 |
| Socio-economic group 2 | 1,775 | 1,871 |
| Socio-economic group 3 | 10,675 | 11,330 |
| Socio-economic group 4 | 49,840 | 52,125 |
| Socio-economic group 5 | 154,781 | 163,813 |
| **Total** | **218,573** | **230,721** |

**Table 4.9: Area of cloth to clothe 100,000 sample population collated by socio-economic group**

The database generously provided by Kemp and the Amarna textile team, published on the web, has been used to assess the various qualities of cloth used to make garments within each socio-economic group. It gives the yarn diameters and warp and weft counts of 3,385 textile samples found in the Workmen's Village at Amarna.[568] My hypothesis is that the range of yarn diameters used by the Egyptians reflects the quality of cloth used to make the wardrobe for each of the socio-economic groups (the finer the linen cloth, the higher up the social scale of the owner). The percentage distribution of yarn diameters is shown in the table below.[569]

[567] The source data for this is the last column in Report 4.5a in CLOTHCALC.
[568] The number of samples found in Amarna total 4962 as of 2001, but only 3,385 samples were in a sufficient state of preservation for measurements to be made.
The source data is taken from the web based database published in Kemp 2001.
[569] Midgley 1911: 37-39. For convenience hereafter the average diameter of the sample range is used for reference and calculations purposes.

| Range yarn diameters mm (n=3,385) | Average yarn diam. mm | % |
|---|---|---|
| 0-0.2 | 0.15 | 14.9 |
| 0.2-0.3 | 0.25 | 71 |
| 0.4-0.6 | 0.5 | 12.9 |
| 0.6-0.9 | 0.75 | 1 |
| Greater Than 0.9 | 1 | 0.2 |
| | | 100 |

**Table 4.10: Yarn diameters measured from 3,385 samples from the Amarna Workmen's Village**

The variation in the quality of cloth used by each socio-economic group in its wardrobe has also been assessed. As a generalisation, the smaller the diameter of the yarn used, and the greater the warp and weft count, the more fine is the cloth.[570] The finer the cloth, however, results in a longer length of yarn which takes more time to produce using Egyptian splicing.[571] Many of the élite are depicted in tomb paintings wearing garments made from a fine sheer cloth, as the body can be seen through the material (Figure 4.39).[572] It is unlikely that these depictions were representative of every day wear. Egyptian tomb paintings were funerary in nature and therefore presented an idealised image as discussed earlier in Section 4.2.1.

My starting point is the assumption that the textile samples found at Amarna reflect the textile types worn by the royal tomb workers and are representative of the garments worn by socio-economic group 4 (skilled craftsmen). For the high élite the percentages in Table 4.10 have been skewed to reflect a greater demand for finer cloth.[573] Similarly, it has been assumed that the farm workers' socio-economic group 5 used coarser yarns in their clothing. The result of the percentage distribution of yarn diameters is given the table below.

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[570] Jones 2006: 140 and Kemp and Vogelsang-Eastwood 2001: 99-103 both propose benchmarks to define cloth quality. Ultra-fine would be have warp counts greater than 80 per cm, fine 60 per cm, down to 5 per cm for coarse cloth. Another measure of quality suggested is a function of the relative density of the warp and weft yarns and their diameters (Kemp and Vogelsang-Eastwood 2001: 99). Stoll and Fengel 1988: 153-159, Table 1, have measured 45 Egyptian linen samples dating from the First Dynasty to the Thirtieth Dynasty and have measured for each, the weight (mg/cm$^2$) and the tex (g/km), indicative of density and diameter respectively.

[571] The Egyptians were capable of weaving extremely fine linen cloth. One piece of cloth owned by Hatnofer, Senenmut's mother was 5.15 m long and 1.6 m long wide, yet only weighed 0.14 kg. The cloth had 4600 warp threads/m and 3000 weft threads/m (Roehrig 1996: 22, endnotes 64-65). This sheet is now owned by the Metropolitan Museum of Art, New York (acquisition number MMA 36.3.111). Splicing is the Egyptian method of producing thread from flax fibres which was different from the more widely practiced in the Eastern Mediterranean using a drop spindle. Splicing will be discussed in more detail later in Section 4.9.1.

[572] Hofmann 1995: Plate IX.

[573] The individual percentages have been increased for the smaller diameters while the total remains at 100%.

| Socio-economic groupings | Percentage distribution of yarn diameters mm | | | | | Total | Area of cloth m² |
|---|---|---|---|---|---|---|---|
| | 0.15 | 0.25 | 0.5 | 0.75 | 1 | | |
| Socio-economic groups 1 | 35 | 55 | 9 | 1 | - | 100 | 1,502 |
| Socio-economic groups 2 | 29 | 60 | 10 | 1 | - | 100 | 1,775 |
| Socio-economic groups 3 | 16 | 72 | 11 | 1 | - | 100 | 10,675 |
| Socio-economic groups 4 | 14.9 | 71 | 12.9 | 1 | 0.2 | 100 | 49,840 |
| Socio-economic group 5 | - | 10 | 30 | 45 | 15 | 100 | 154,781 |
| | | | | | | | 218,573 |

**Table 4.11: Estimated percentage distribution of yarn diameters collated by socio-economic group**

It has been stated above that this thesis assumes that the fineness of the cloth is proportional to the diameter of yarn used. Therefore the resulting matrix of yarn diameter percentages, summarised in Table 4.11, can be used to proportion the area of cloth used by each socio-economic group. In the table above, 71% of threads from the 3,385 samples measured had an average diameter of 0.25 mm. Therefore for socio-economic 4 the area of cloth having a yarn diameter of 0.25 mm would be the 49,840 (area of cloth for group 4) × 71 (percentage for this socio-economic group) ÷ 100, which equals 35,386 m². The results of applying the same methodology to all socio-economic groups and cloth types are given in the table below.[574] The sum of the areas equals 218,573 m² as the total area required clothing 100,000 people.

| Socio-economic groupings | Egypt | | | | | |
|---|---|---|---|---|---|---|
| | Area of cloth collated by average yarn diameter mm. | | | | | Area of cloth m² |
| | 0.15 | 0.25 | 0.5 | 0.75 | 1 | |
| Socio-economic groups 1 | 526 | 826 | 135 | 15 | - | 1,502 |
| Socio-economic groups 2 | 515 | 1,065 | 178 | 18 | - | 1,776 |
| Socio-economic groups 3 | 1,708 | 7,686 | 1,174 | 107 | - | 10,675 |
| Socio-economic groups 4 | 7,426 | 35,386 | 6,429 | 498 | 100 | 49,840 |
| Socio-economic group 5 | - | 15,478 | 46,434 | 69,651 | 23,217 | 154,780 |
| **Totals** | **10,175** | **60,441** | **54,350** | **70,289** | **23,317** | **218,573** |

**Table 4.12: Area of cloth (Egypt) grouped by average yarn diameter and socio-economic group**

## Factor 2: Length of yarn required to make one metre of cloth

To estimate the length of yarn required to make one square metre of cloth, typical warp and weft counts used in antiquity are used. In Kemp's 2001 database, 2,582 samples were in a state of preservation that enabled wefts and warps to be counted. This data was transposed into the Warps and Wefts worksheet in CLOTHCALC (Reports 4.6a-4.6h) and the warp and weft counts correlated to the yarn diameters used above. The distribution within each diameter band is not normal, so the median

[574] The database written to collate the Kemp 2001 source data is found in worksheet Amarna diameters in spreadsheet CLOTHCALC.

is used rather than a simple average.[575] The warps and weft counts per metre for the 1 mm diameter yarn is extrapolated from the others, as only two samples greater than 0.9 mm were in a good enough state of preservation to be measured. The results are tabulated in the table below.

| **Av. yarn diam mm (n=2,582)** | **Median warps/m** | **Median wefts/m** |
|---|---|---|
| 0.15 | 2,940 | 1,690 |
| 0.25 | 2,260 | 1,230 |
| 0.5 | 1,760 | 950 |
| 0.8 | 1,010 | 810 |
| 1 | 800 | 500 |

**Table 4.13: Average warp and weft counts in 2,582 samples collated by yarn diameter**

When estimating the length of yarn required weaving a given area of cloth, allowance must be made for the shrinkage of woven cloth when it is taken off the loom. During the weaving process, the weft goes over and under the warps drawing them closer together. This is called the 'take-up' and could be as much as 10% in the weft and 8% in the warp. In addition, as with all natural fibres, when the cloth is washed shrinkage occurs. For flax this is typically 6% in the weft and 8% in the warp. Therefore to produce a finished piece of cloth one metre square, the weft and the warp on the loom must both be set to lengths of 1.16 m. A length of 0.8 m must be added to the warp for tying off, making a length of 1.96 m for each warp.[576]

Knowing the median of the weft and warp counts, and multiplying them by the lengths of a single weft and warp identified above (0.8 m and 1.96 m respectively), the total length of yarn required to make one m$^2$ of cloth can be calculated. For example for the cloth using yarn with an average of 0.15 mm diameter, the average values for the weft and warp counts were 2,940/m and 1,690/m respectively. The length of yarn to make one square metre of cloth would be (2,940 × 1,690) + (1,690 × 1.16) = 7,722 m. For the full range of yarn diameter bands see the table below.

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[575] The median is found by sorting the data array in increasing order, and taking the middle value. It has the property that in the data array there are as many greater numbers as smaller values than the median. The median is more representative than a simple average when the distribution is not normal. For a normal distribution the area enclosed within the distribution either side of the average is equal in magnitude.

[576] Petrini 2006. For the full analysis see Report 4.6b in CLOTHCALC.

| Average diameter of yarns mm | 0.15 | 0.25 | 0.5 | 0.75 | 1 | mm |
|---|---|---|---|---|---|---|
| Av. warp count/m of 2,582 Amarna samples | 2,940 | 2,260 | 1,760 | 1,010 | 800 | per m |
| Av. weft count/m of 2,582 Amarna samples | 1,690 | 1,230 | 950 | 810 | 500 | per m |
| Length of weft thread to make 1 sq m of cloth | 1,960 | 1,427 | 1,102 | 940 | 580 | m |
| Length of warp thread to make 1 sq m of cloth | 5,762 | 4,430 | 3,450 | 1,980 | 1,568 | m |
| **Tot.length of yarn required to make 1 m²** | 7,722 | **5,857** | **4,552** | **2,920** | **2,148** | **m** |

**Table 4.14: Length of yarn required to make one m² of cloth grouped by yarn diameters**

## Total length of yarn required correlated by socio-economic group

Multiplying the square metres of cloth required by each socio-economic class (Table 4.12) by its respective length of yarn (Table 4.14), the total length of yarn for all socio-economic groups can be calculated.[577] A summary for all socio-economic groups collated by yarn diameter is given in the table below.

| **Total length km of yarn required for Egypt collated by socio-economic groups** | | | | | |
|---|---|---|---|---|---|
| **Yarn diams mm categories 1-5** | **0.15** | **0.25** | **0.5** | **0.75** | **1** |
| Socio-economic groups 1 | 4,062 | 4,838 | 615 | 44 | - |
| Socio-economic groups 2 | 3,977 | 6,238 | 810 | 53 | - |
| Socio-economic groups 3 | 13,189 | 45,017 | 5,344 | 312 | - |
| Socio-economic groups 4 | 57,344 | 207,256 | 29,265 | 1,454 | 215 |
| Socio-economic group 5 | - | 90,655 | 211,368 | 203,381 | 49,870 |
| **Total length of yarn km** | **78,572** | **354,004** | **247,402** | **205,244** | **50,085** |
| | | **Egypt - total length (km)** | | | **935,307** |
| | | **Cyprus- total length (km)** | | | **986,296** |

**Table 4.15: Length of yarn m required to meet the demand for cloth**

The sum of all these lengths needed to provide sufficient yarn to clothe 100,000 people comes to a staggering length of yarn, 935,307 km. This explains why the cloth-making industry was so labour intensive, and why cloth was so highly valued.

## Factor 3: Weight of yarn required to clothe 100,000 people

No data is available for the weight of extant yarns from antiquity, so estimates are used from modern published data. The nearest modern equivalent to the 0.5 mm diameter band yarns from Amarna is Londerry 50/3 yarns and this yarn has been taken for this study as the modern equivalent.[578] The analysis of the Amarna yarns

[577] Taking as an example cloth made with the yarn diameter 0.15 mm, the area of cloth required for socio-economic groups 4 was 7,426 m² (Table 4.12). The length of two-ply yarn required to make one m² of cloth using yarn of 0.15 mm diameter (Table 3.14) equals 7,722 m. Multiplying these two together gives the total length of 0.15 mm yarn used by socio-economic group 4 as 7,426 × 7,722÷ 1000 = 57,344 km of yarn.

[578] By convention the first number is an indicator of weight. The lower the number, the greater the weight of yarn per unit length. The second number indicates the number of threads in a plied yarn. Hereafter this convention will be used in this chapter.

showed that over 98% were two-ply yarns.[579] The length of 40/2 yarn that can be made from one kg of flax yarn is 302.7 m/kg which is 25% higher than 50/3 yarn.[580] The length of yarn/unit weight of yarn m/kg and the weight (kg) of one metre of yarn collated by yarn diameter is given in the table below.[581]

| Average Amarna diameters | **0.15** | **0.25** | **0.5** | **0.75** | **1** |
|---|---|---|---|---|---|
| Nearest modern equivalent | 160/3 | 130/3 | 50/3 | 20/3 | 18/3 |
| Muktiplying factor | 160 | 130 | 50 | 20 | 18 |
| Length of yarn to make 1 kg yarn | 32280 | 26228 | 10088 | 4035 | 3632 |
| Weight of one m of 3 ply yarn kg | 3.1E-05 | 3.81E-05 | 9.91E-05 | 0.000248 | 0.000275 |
| Length of yarn to make 1 kg yarn | 32280 | 26228 | 10088 | 4035 | 3632 |
| Weight of one m of 3 ply yarn kg | 3.1E-05 | 3.81E-05 | 9.91E-05 | 0.000248 | 0.000275 |

**Table 4.16: Estimated weight of one m$^2$ of cloth for all Amarna diameter bands**

## Total weight of yarn required to clothe 100,000 people

The total weight of yarn required to clothe 100,000 people is calculated by multiplying the total length of yarn required (Table 4.15) by the weight of one m of yarn (Table 4.16). This weight is grouped by yarn diameter and socio-economic group in the table below.[582]

| **Egyptian Socio-economic groupings** | **Wt. of yarn collated by yarn diams. mm** | | | | | **Wt of yarn kg** |
|---|---|---|---|---|---|---|
| | **0.15** | **0.25** | **0.5** | **0.75** | **1** | |
| Socio-economic groups 1 | 126 | 185 | 61 | 11 | - | 382 |
| Socio-economic groups 2 | 123 | 238 | 80 | 13 | - | 454 |
| Socio-economic groups 3 | 409 | 1,716 | 530 | 77 | - | 2,732 |
| Socio-economic groups 4 | 1,777 | 7,902 | 2,901 | 360 | 59 | 12,999 |
| Socio-economic group 5 | - | 3,456 | 20,952 | 50,404 | 13,731 | 88,543 |
| **Total weight of yarn kg** | **2,434** | **13,497** | **24,524** | **50,865** | **13,790** | **105,110** |
| **Cypriot Socio-economic groupings** | **Wt. of yarn collated by yarn diams. mm** | | | | | **Wt of yarn kg** |
| | **0.15** | **0.25** | **0.5** | **0.75** | **1** | |
| Socio-economic groups 1 | 133 | 251 | 64 | 12 | - | 459 |
| Socio-economic groups 2 | 130 | 1,822 | 84 | 14 | - | 2,050 |
| Socio-economic groups 3 | 434 | 8,265 | 562 | 82 | - | 9,342 |
| Socio-economic groups 4 | 1,858 | 3,658 | 3,034 | 377 | 61 | 8,988 |
| Socio-economic group 5 | | 14,189 | 22,175 | 53,346 | 14,532 | 104,242 |
| **Total weight of yarn kg** | **2,554** | **28,185** | **25,919** | **53,831** | **14,593** | **125,082** |

**Table 4.17: Weight of dry yarn/flax fibre required to clothe 100,000 people collated by yarn diameter and socio-economic group**

579 Kemp and Vogelsang-Eastwood 2001: 58-60, particularly Table 3.1and Figure 3.3.

580 The length of modern yarn that can be produced from one kg of yarn are published in Handwoven® Magazine 2007. *Master Yarn Chart.* Accessed 7th July 2007. Available from http://www.interweave.com/weave/handwoven_magazine/files/yarn_chart.pdf. Loveland, Colorado: Interweave Press LLC

581 I am grateful to Denise Davis of the Threadneedle Street Company, Issaquah, WA 98027 USA (www.threadneedlestreet.com) for her assistance in discussing the approach to determine factor 3 and sharing her knowledge of yarn weights.

582 For the full analysis see Module 7 in CLOTHCALC.

## 4.6.3 Area of land required for growing flax

Knowing now the weight of dry fibre required, the area of land needed to grow the flax can be calculated using the formula, weight of flax fibre divided by the flax yield. Egyptian ethnographic evidence dated 1882 A.D. shows the average yield for flax fibre in Egypt in 1884 was 627 kg/ha.[583] The yield of dry fibre is not stated. Caldwell's ethnographic study of rural Egypt in 1931 uses an average green flax yield of 80 cwt/acre (10,050 kg/ha).[584] Section 4.7 below will show that the green flax passes through a number of stages in processing to produce dry fibre. At each stage, water and vegetable matter is lost which results in a final yield of dry fibre of 535 kg/ha.[585] This figure has to be corrected to adjust to farming conditions before the introduction of artificial fertilizers in the latter part of the nineteenth century A.D. As discussed in Section 4.2.6 this would reduce the yield by 36% to 342 kg/ha.[586] The yield from modern Messenia is 804 kg/ha but no attempt has been made to estimate yield rates before the application of fertilisers.[587] McCorriston's estimate for the production of dry flax fibre in Mesopotamia was 335 kg/ha.[588] For this exercise the estimated Egyptian yield will be used for other East Mediterranean regions. The area of land under cultivation using this yield rate is the total weight of flax required, 105,110 kg divided by the yield, 342 kg/ha, giving an area of 308 hectares to satisfy the flax requirement to clothe a population of 100,000. In antiquity, losses in the field would be significant and have been set in CLOTHCALC at 15%.[589] The area of land

[583] Robino 1884: 432
[584] Caldwell 1931: 16.
[585] Caldwell 1931: 16.
[586] This is based on typical fertiliser rates of 150 ardebs/feddan used in rural Egypt in 1937 (Richards 1982: 129-131, table 4.9 citing Nassif, E. 1942. L'Egypte, est-elle surpeuplée? *L'Egypte Contemporaine* 33: 376).
[587] Robkin 1979: 472.
[588] McCorriston *et al* 1997: 524, Table 2.
[589] See earlier discussion in Section 3.3.2 relating to wastage of cereals and pulses through the cultivation and processing processes based on modern ethnographic evidence. Cereals have been assumed to loose 5% in the field and 10% in transport, threshing, and storage. Unlike cereals the losses of flax were not due to vermin. The main cause was the wider variation in standing height of domesticated plants in antiquity compared with modern varieties. This variation is important for this study because the shorter the flax stems the more difficult it is to apply the splicing methods (discussed later in Section 4.9.1) used to produce linen thread by the Egyptians. A scientific study of 83 pale flax plants (*Linum usitatissimum* L. subsp. *angustifollium*), the progenitor of cultivated flax grown from seed has been carried out using seed from the Gatersleben Genebank. They were grown in controlled conditions and key measurements defining the growth pattern were compared with modern flax varieties. Their heights at maturity show an average height of 0.665m with a coefficient of variation of 11.5% percentage (Diederichsen and K. 1995: 263-269 and particularly Table 5). The coefficient of variance is the standard deviation of a group of values divided by the mean and the

required to be under cultivation to provide sufficient flax to clothe 100,000 people would be 355 hectares.

## 4.6.4 Manpower requirements

This section evaluates the manpower required for growing and processing the flax prior to spinning. As with the analysis of manpower requirements for cereals and by pulses, the activities within the process are examined and manpower needs allocated using evidence drawn from Egyptian Tomb paintings and ethnographic evidence of flax production using traditional methods (see again Figure 4.37). Ploughing, hoeing, broadcast sowing, and trampling in of flax seed by sheep follow the same basic pattern as growing cereals. The main differences to growing flax being the amount of irrigation required to sustain growth and the importance of frequent weeding particularly in the early stages of growth.

### Manpower required to grow flax

Two cases are considered to assess the manpower necessary to prepare the land to grow flax. The first case (hereafter case A) supposes the soil was prepared by ploughing and the second (hereafter case B) that the soil prepared by hoeing. The total man-days expended in soil preparation, sowing and weeding equals the total man-days/hectares identified above multiplied by the number of hectares under flax cultivation. There is little difference in the soil preparation for flax and cereals (as discussed in Section 3.4.1) and the model will use the same time file man-days/hectares to complete this work. To reflect the increased time required for weeding, as discussed above, the model will assume that weeding took three times as long for flax as it did for cereals.[590]

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result multiplied by 100 to give a percentage. This variation in standing height would mean that wastage would occur because the length of fibre after retting would be too short for the splicing of the bast fibres practiced by the Egyptians. Added to this there would be an inevitable wastage during harvesting and transporting the green flax to the site of the retting process. While this cannot be quantified exactly, a value of 15% for wastage seems reasonable and this value is used in CLOTHCALC.

[590] The time spent on flax is 242 man-days/hectares compared with 198 man/days assumed for wheat as discussed in Section 4.4.5.

Columella states that the harvesting of one iugerum of flax took three days to complete (0.0833 hectares/day or 12 man-days/hectare).[591] This compares well with Irish ethnographic evidence where the rate of hand pulling of flax averaged 0.101 hectares/day (10 days/hectare).[592] The model will use Columella's assessment on the time taken to hand pull flax reflecting the more adverse farming conditions in antiquity. Following harvesting the cut flax was allowed to dry in the sun with the seeds continuing to mature. A summary of the man-days required for flax cultivation is given in the tables following.

| | |
|---|---|
| First ploughing man-days/ha | 12 |
| Second ploughing man-days/ha | 6 |
| Tertiary ploughing man-days/ha | 5 |
| Sowing estimate man-days/ha | 3 |
| Harrowing man-days/ha | 5 |
| Weeding estimate man-days/ha | 27 |
| Harvesting man-days/ha | 13 |
| Irrigation man-days/ha | 171 |
| **Tot. agricultural man-days/ha** | **242** |

**Table 4.18: Case A, Man-days required cultivating sufficient flax to satisfy the domestic demand for cloth (ploughing case)**

Similarly, for hoeing, the total number of man-days required to grow one hectare of flax would be equivalent to 304 persons.

| | |
|---|---|
| Hoeing man-days/ha | 83 |
| Sowing estimate man-days/ha | 3 |
| Harrowing man-days/ha | 7 |
| Weeding estimate man-days/ha | 27 |
| Harvesting man-days/ha | 13 |
| Irrigation man-days/ha | 171 |
| **Total agricultural man-days/ha** | **304** |

**Table 4.19: Case B, Man-days required cultivating sufficient flax to satisfy the domestic demand for cloth (hoeing case)**

Using the same utilisation factors to convert workload to manpower as Section 3.4 in Chapter 3, and the same ploughing to hoeing ratios as used in Section 3.5.3 of Chapter 3, the total manpower required is as shown in the table below.

| **Manpower requirements** | **Egypt** | |
|---|---|---|
| Ploughing assumption | 30 | % |
| Hoeing assumption | 70 | % |
| **Manpower requirement to cultivate flax** | **329** | **people** |

**Table 4.20: Manpower required growing sufficient flax to cloth 100,000 people for Egypt and Cyprus**

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[591] Columella *de r.r.* 2.12.
[592] Forbes 1956: 28.

# 4.7 Preparation of flax ready for spinning

This section will discuss the process carried out in antiquity to convert post-harvest green flax into flax fibre suitable for spinning.[593] The process will be broken down into four discrete operations (rippling, retting, scutching, and hackling), and for each the manpower implications will be identified and quantified.[594] Egyptian tomb paintings are used to identify the process, but where there are gaps in iconographic evidence, ethnographic and experimental archaeology have also been used.

After an extensive search of the relevant literature, it has not proved possible to find any data regarding time taken and the number of individuals required to prepare the harvested flax for spinning. To fill this gap, an experiment was devised to replicate the process. The objective of the experiment was to replicate rippling, retting, scutching, and hackling and estimate the time taken to complete each operation so that from this information the manpower required in antiquity could be estimated.

For the first experiment, access to ripe green flax was not possible, so the initial experiments (seven samples) used other bast grasses and nettles, which were chosen to replicate the main characteristics of flax, that is, fibrous in nature, with a hard outer shell and an approximate standing height of 0.8-1 m. At a later date, after the UK flax harvest, an additional three samples of recently-harvested flax were analysed. No significant difference in weights/unit length was observed (Report 4.11b).

## 4.7.1 Rippling and retting

The first operation was to remove the seed heads from the flax with a wooden comb (rippling), before gathering into bales (Figures 4.40-4.41). The Ancient Egyptian word for bale of flax was *nwyt*, and this was made up of 60 *š3rw* (sheaves). Each sheaf was equivalent to the quantity which could be held in an adult male hand.[595] Two tightly-packed bales of flax, measuring 0.25 m in diameter and 1 m in length, have survived in archaeological records and are on display in the Agricultural

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593 To avoid confusion between flax harvested in the field and the yield of fibre after processing, it is the convention to refer to the former as green flax. Hereafter this thesis will follow the same convention.

594 Rippling, retting, scutching, and hackling operations will be discussed in the following sections.

595 Allen 2002: 172-173, footnotes 148-151.

Museum of Doqqi in Cairo (Figure 4.41). The size of a bale and its weight are important for two reasons. The first is that the bale must be of a weight which could be carried by an adult male across the shoulder (see again Figures 4.40). A bale of harvested flax the size of the Doqqi examples was made up of approximately 60 handfuls of flax, called 'sheaves'.[596] The experimental results of the author show that the average weight of 10 tight handfuls of bast material, each with an average length of 0.8 m, is 0.36 kg. This would mean that a bale of 60 sheaves would have a dry weight of 21 kg.[597] The second reason is that flax was taxed in Egypt, and it would have been necessary to standardise weight and volume to enable the expected harvest forecast by tax officials to be reconciled with the harvest that was actually achieved. Using a base unit of a handful of flax seems a very practical way of ensuring bales made up of 60 handfuls were of comparable size, thus making tax reconciliation a simple logistical exercise. A bale of 60 sheaves would therefore fulfil both of these needs.

The tied bales of flax were then immersed in water to allow the inner core to rot, a process which is called retting.[598] Retting can be carried out in running water, and will rot the cortical tissue of the plant within a period of 10-14 days.[599] Retting in stagnant water is faster as the flora and fauna bacteria aid the fermentation process.[600] Lifting the bundles of retted flax out of the water as a wet bale would have taken significant manual effort, and bales would weigh significantly more than the 21 kg dry weight. For the purposes of this thesis, it has been estimated that this was at least twice the weight of a dry bale (42 kg), and at least two people would be

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[596] Allen 2002: 172-173, footnotes 148-151. A man's hand can hold a roll of flax stems of an approximate area of 0.00101801 $m^2$ (0.036 m diameter), and, when tied tightly in a bale, this area is reduced to 0.000804 $m^2$. Using the Doqqi example, the cross-sectional area of a bale is 0.0491 sq cm. Dividing the area of the bale by the area of a compressed handful provides a close approximation of 60-61 sheaves per bale, a possible base unit of taxation accounting in the time of Heqanakht (Middle Kingdom).

[597] This experiment was carried out by the author using flax stems after harvest in West Overton, Wiltshire. Analysis of the experimental results are given is given in Report 4.11b in CLOTHCALC.

[598] Note the scene in the Middle Kingdom Tomb of Amenemhat (Tomb No. 2) at Beni Hassan (Newberry 1983: 31, Plate XI is sometimes erroneously cited as an example of the retting and scutching operations. It is now considered that this scene depicts part of the laundry process.

[599] Vogelsang-Eastwood 2000: 271.

[600] Leadbeater *et al* 1976: 59.

required to carry out this process. The retted flax was laid out in the sun to dry, which helped to break down any remaining adhesive substances in the flax.[601]

The proportion of fibres suitable for spinning compared to the weight of the harvested green flax is surprisingly small. In the table following analyses the loss by weight of plant material removed for each stage of the fibre preparation process. It can be seen in the table below that the finished fibre is only 5.3% by weight of the original green flax.[602] It is unlikely that this material was discarded, as it was probably used for other purposes such as fuel, thatch and fodder.[603]

| Activity. Source data Caldwell 1931: 16. | Yield kg/ha | %of initial weight |
|---|---|---|
| Weight of green flax post harvest | 10,050 | |
| Weight after loss of water drying | 4,525 | 45.0 |
| Weight loss de-seeding | 905 | 9.0 |
| Weight loss retting | 905 | 9.0 |
| Less hackling and scutching | 3,180 | 31.7 |
| **Wt. of fibre ready for spinning** | **535** | **5.3** |

**Table 4.21: Losses incurred in the flax preparation process**

To work out the manpower requirements, the weight of flax at each stage of the process has been calculated. Section 4.6.1 above has shown that the weight of finished fibre required to produce the area of cloth to clothe 100,000 people was 105,110 kg. Using the relationship stating that 5.3% of the original green flax harvested remains after processing (Report 4.8d), we can prorate this dry fibre requirement back to the original green harvest weight as follows $105{,}110 \times 100 \div 5.3 = 1{,}983{,}213$ kg (Report 4.8f).

## Manpower required to remove seed heads (rippling)

A wooden comb thought to have been used for rippling is shown in Figure 4.42. From the tomb evidence (Figure 4.40) and a critical examination of the rippling process, it makes ergonomic sense that that one handful was processed at a time. The

[601] Leadbeater *et al* 1976: 59.
[602] Source data from Caldwell 1931: 16. The conversion factor used to convert Caldwell's imperial units to metric units is 1 cwt/acre = 125.64 kg/hectare. Leadbeater *et al* 1976: 56 state that modern flax fibre yield after processing is 9-10% of the green flax harvest yield. The initial yield of green flax harvested in one hectare = 10,050 kg. The weight of fibre ready for spinning after processing would weigh 535 kg, and the percentage of useable fibre compared with harvested green flax yield = $100 \times 535 \div 10{,}050 = 5.3\%$.
[603] Hadfield 1953: 7 emphasises the economic importance in modern agriculture of flax tow (small lengths of flax fibre), seed bolls (heads), immature seed, shive (outer woody bark layer) and chaff.

author's own experimental results show that the average weight of ten handfuls of flax would be 0.36 kg, and so the total number of handfuls would be = 1,983,213 ÷ 0.36 = 5,509,000 handfuls. A process time of 45 seconds to pick up a handful of harvested flax, remove the seed heads and place it in a pile ready to tie up into a bale seems a reasonable estimate. Using a process time of this figure, the total time spent rippling would be = 5,509,000 × 45 ÷ (3600 × 9) = 23 man-years, working a 9 hr day. This is equivalent to the effort of 13 men working full time for a year.[604] Report 4.8f estimates the total man-days required to tie and carry the green flax bales after rippling to the water for retting and to lift them from the water post-retting, and shows that a minimum of ca. 23,086 man-days was required, given a 9 hr working day, which is equivalent to 69 men working for a year.

## Scutching and hackling

The retted flax was dried in the sun before scutching (bruising the retted flax stems) by beating, the purpose of which was to remove any of the woody outer bark remaining after retting. The rotted flax was probably placed onto a large stone and hammered with wooden mallets, but this is not supported by tomb evidence, though wooden mallets have been found in archaeological records.[605] A mallet thought to have been used for beating the flax and a comb for hackling (discussed below) are on display at the Doqqi Museum, Cairo (Figure 4.43), and certainly their design and weight would have made them ideal tools for bruising the flax stems.[606] Ethnographic evidence from 1931 A.D. supports this suggestion, wooden mallets being used to bruise flax stems in the Upper Egyptian village of Nahya (Figure 4.44).[607] When fully beaten, the fibre was stripped (hackled) from any remaining vegetable matter using a different design of wooden comb to that used for rippling (Figure 4.46).[608] The Twelfth Dynasty Tomb of Daga at Thebes shows women separating the fibres and splicing them into long continuous threads prior to

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[604] For the full analysis, see Report 4.8e.
[605] Vogelsang-Eastwood 2000: 271.
[606] Brewer, Redford and Redford 1994: 1994: 37, Figure 4.4. The wooden mallet and comb cannot be directly linked to flax preparation, as their provenance is uncertain.
[607] Vogelsang-Eastwood 2000: 271 citing Crowfoot, G.M. 1931. *Methods of Hand Spinning in Egypt and the Sudan*. Halifax: Bankfield Museum Notes.
[608] On display at the Agricultural Museum, at Dokki, Giza is an ancient mallet thought to have been used for beating flax, together with a comb, the probable use of which was to separate and clean the flax fibres. However, the provenance is unknown, so the mallet could have been used for any purpose. The comb, however, certainly looks functionally capable of dividing the flax fibres.

spinning.[609] This tomb painting suggests that a comb was not used for hacking, but instead the bruised flax stem was passed through two pieces of wood to remove unwanted matter (see women hackling on extreme left-hand side of Figure 4.45).

The author experimented with beating available bast vegetation using the same techniques as Leadbeater, who found that beating one handful at a time was the optimum ergonomic quantity.[610] Each bundle was beaten with a wooden mallet for an average of 2 minutes to ensure the unwanted woody part of the stems was separated from the bast type fibres. If the bast material had been fully retted, this time would probably have been reduced to some two minutes, and this value has been used in the analysis (see Report 4.11a in CLOTHCALC). Each handful was hand-cleaned (scutching) to remove broken stems and debris following the beating, which took on average 2.5 minutes per handful. The tool used in antiquity to hackle the fibres is not established beyond doubt, but Leadbeater's experimental archaeology used a comb made from wood and nails.[611] The photographs suggest that this operation would have required the passing of the retted stems many times to produce the fine fibres suitable for spinning (Figure 4.46). This analysis has assumed the operation took four minutes per handful, which would give a total time for beating, scutching and hackling of 8.5 mins (Report 4.11a). At these rates it would have taken 7.42 hrs of continuous work to prepare 1 kg of flax fibre. Using this rate to process the total weight of dry fibre required to clothe a 100,000 sample population (105,110 kg), it would take 86,658 man-days of effort, assuming a 9 hour working day.[612]

In summary, the total workload required to prepare sufficient dry fibre, ready for spinning, to clothe 100,000 people would have been 342 man-years.

| Operation | Man-years |
|---|---|
| Rippling | 23 |
| Binding and retting | 69 |
| Skutching and hackling | 250 |
| **Total** | **342** |

**Table 4.22: Summary of the workload required to prepare flax fibre to clothe 100,000 people**

609 After Barber 1991: 45, Figure 2.5.
610 In particular, see Leadbeater *et al* 1976: 60-61, Figures 4.16 - 4.20. Unfortunately no timings were published, which would have aided comparison with the author's experimental results.
611 Leadbeater *et al* 1976: 61, Figure 4.2.
612 See Report 4.11a.

# 4.8 Manpower required wool production

This chapter will examine the LBA woollen industry in order to identify the main differences in manpower requirements for husbandry of sheep and the production of woollen cloth, compared with the processes involved in making linen. For most regions in the Eastern Mediterranean, wool rather than flax dominated the LBA cloth industry. There were sizable linen production centres in Pylos and in Mesopotamia.[613] In Mesopotamia the principal areas of linen production were Ur and Lagash, which supplied approximately 10% of the total demand for textiles.[614] The wild ancestors of the domesticated sheep of the LBA in the Eastern Mediterranean were probably the mouflon that populated north-western Iran.[615] It can be assumed that wool was the major fibre of choice in the LBA outside Egypt.

Wool is a protein fibre chiefly composed of keratin. The fibre is made up of overlapping cuticle scales and an inner cortex, and is slightly elliptical, unlike other animal fibres.[616] Primitive sheep had a complex coat made up of kemps, hair and wool fibre.[617] Wool fibres are classified into two groups; "medium" with diameter ranges 30-60 microns, and "fine" with diameters under 30 microns[618].

The choice between wool and flax was not driven principally by the preference for wool or linen by the consumer, with the possible exception of the high elite, but instead by more pragmatic requirements that had to be satisfied.[619] Particularly relevant to Egypt was the lack of grazing land for large flocks of sheep, and other regions lacked adequate water supplies for flax to thrive. Some regions also lacked the social cohesiveness necessary to organise the peak manpower requirements for weeding flax in the growing season.[620] Sheep in antiquity had wide colour variation

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[613] Killen 1984: 49-63, Killen 1993: 209-218, Jacobsen 1970: 422-427, Renfrew 1985: 63-66, McCorriston *et al* 1997: 517-549, and Wild 2003c: 43-47.
[614] Waetzoldt 1980-1983b: 583.
[615] Ryder 1983: 20-21. The transferring gene frequencies of the wild sheep of north-western Iran most closely resembled those of domestic sheep.
[616] Petrie 1995: 6.
[617] The kemps are coarse, bristle-like hairs that are brittle and unsuitable for spinning. Hairs can be spun if they are mixed with wool fibre. Kemps are normally within the range of 100-150 microns in diameter, while hairs are between 50-100 microns (Wild 2002: 5).
[618] Barber 1991: 21.
[619] In Mesopotamia, Mari texts show that linen was a high-status item used for wall hangings, table cloths, throne coverings, bed coverings and medical bandages (Waetzoldt 1980-1983b: 592-593).
[620] Flax is particularly vulnerable to competition from weeds for water, sunlight, and nutrients.

on different parts of the animal, and naturally-pigmented wool is difficult to dye, and this provided an advantage for linen production as a source of coloured, patterned cloth, particularly for the elite.[621]

To increase our understanding of whether wool required more or less manpower to produce cloth than flax, a number of factors have to be considered and quantified. The first factor is the weight of wool that can be taken from a given animal in one season, and the second is the amount of wool required to make a unit area of cloth. Both of these dictate the size of the flocks and the number of shepherds required for their husbandry. The final consideration is the time required to comb out a unit weight of wool in preparation for spinning and the time taken to spin the drafted woollen fibre into thread. This section will discuss these points in the above order.

## 4.8.1 Evidence of wool yields in antiquity

Neo-Sumerian texts show that the numbers of sheep reared for wool could have been very large, as demonstrated in the Gir-su region, where 66,095 fat-tailed state-owned sheep were reported in the 36th year of Shulgi (2011 B.C.).[622] The fleece of sheep bred in the third and second millennia moulted in summer and enabled the wool to be removed by plucking.[623] Some wool was shed and unavoidably lost in their natural habitat.[624] A number of texts have survived from the period, which helps us to determine the wool yield per animal per year.

### Mesopotamia

The Mesopotamian fat-tailed uli-gi sheep produced on average an off-the-animal wool weight of 0.707 kg.[625] Black sheep could produce higher wool yields of 1.01 kg/animal, but the quality of this dictated that it was used mainly for coarse cloth.[626]

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[621] Barber 1991: 29. By the LBA, through domestication and selective breeding, sheep fleeces became increasingly less patchy in colour, producing a higher proportion of white wool.
[622] Waetzoldt 1972: 17.
[623] As wool was gathered mainly by plucking in the LBA (see later discussion), it should be noted that the entire fleece was not removed. Hereafter the term 'off-the-animal weight' refers to the weight of wool gathered by this method, in contrast to the much greater weight of the entire sheep fleece that is possible to obtain in modern husbandry through shearing.
[624] Wild 1970: 7.
[625] Waetzoldt 1972: 18.
[626] Jacobsen 1970: 423, endnote 10 and Waetzoldt 1972: 50-51.

Liverani's review of Mesopotamian textual evidence suggests that a range of 0.7 to 1.1 kg could be obtained from one sheep.[627]

## The Aegean

Killen suggests that an average of 0.75 kg/animal is representative of LBA Crete[628]. This is in line with wool yields in modern Crete, where 0.5-1 kg of wool can be obtained, depending on the size of the animal.[629] Young's analysis of the Knossos Dk series of tablets indicates an average yield of 0.56 kg of wool per animal.[630] The wide variation in yields from textual sources was probably due to the fact that wool was plucked from the animals.[631] Surviving textual records are inevitably a question of chance; particularly in the case of the evidence given above, which covers a wide time span, a variety of breeds, not to mention the uncertainty of the make-up of flocks (i.e. proportions of rams, ewes, lambs and or wethers).[632] A possible check is Killen's analysis of Linear B sign *145 from the Knossos tablets.[633] Killen proposes that this sign was a unit of account that applied only to wool. This value comparator was 3 kg of wool, which could be obtained from four sheep, implying that the wool yield was 0.75 kg/animal.[634] The Nuzi texts show that they had an almost identical

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627 Liverani 1979: 70, note 69. The wool from a single sheep as noted in the Alalakh tablets weighed 100 shekels, which in modern weights is equivalent to 0.73 kg. The weight of wool from 308 sheep gave an average weight of 100 shekels (0.73 kg), of which 12% was of no practical use according to this text (Wiseman 1953: 100 translation of text ATT/8/246.). Alalakh was a city state situated at Tell Aýšan (Atchana in modern Turkey), in the Amuq Plain, east of the river Orontes. Its first palace was built ca. 2000 B.C., contemporary with UR III, and it was destroyed by the Sea Peoples ca. 1200 B.C., having previously been occupied by the Hittites and the Mitanni.
628 Killen 1964: 9.
629 Young 1965: 113.
630 For comparison in 14th century England yield rates were 0.68 kg/animal for mixed flocks and 0.8 kg/animal for wethers (castrated male sheep) alone (Drew 1947: 30).
631 Burke 1997: 108.
632 The relevance of this is that wethers provide better meat than rams, are less prone to disease than ewes, and provide between 60-100% more wool than ewes, depending on the strength and age of the animal (Killen 1964: 5; footnotes 30, 58.
633 See also Ventris and Chadwick 1973: 203-204, who first proposed that *145 was a wool unit equivalent to about 3 kg.
634 Killen 1962: 38-72, Killen 1964: 13-15, Killen 1968: 105-123, Killen 1969: 23-38, and Killen 1993: 209-218. For the counter-argument, see Young 1965: 111-122 and Young 1969: 39-42. Young argues that the Dk and Dl tablets do not consistently suggest a 4:1 ratio, particularly as they refer to different flocks of rams, ewes, lambs and wethers. Petruso supports this proposal in his metrological analysis of the Knossos *145 sign, showing that it was equivalent to three double minas (3 x 0.964 = 2.892 kg), or one tenth of a talent (Petruso 1986: 26-37). Burke 1998:109 corrects the misprint in Petruso 1986: 27, namely that a double minas was 2.892 kg, not 2.982 kg as printed. When referencing Petruso's work hereafter, the amended value will be used. The talent weighed 28.9 kg and by convention is designated L (LANA). Its use as a unit of weight and a value comparator, particularly in the LBA copper trade, is discussed in Zaccagnini 1986: 413-424. Other units used by

measure for this weight of wool, called the *nariu* (3 kg), which again could be obtained from four sheep.[635] Using the consensus average value that the wool yield was 0.75 kg/animal, it follows that four sheep would produce 3 kg which is so close to the Mycenaean *145 wool unit of account (3 kg) and the Nuzian wool unit of account (2.892 kg). This seems too much of a coincidence that they were not almost identical measures of wool, despite the evidence came from different cultures. This argument is strengthened by considering the size of a bale of wool weighing one LANA or one *nariu*. The wool taken from a Soay sheep weighed 0.454 kg, and, when rolled, had an enclosed volume of 0.007636 $m^3$.[636] To produce a weight of one LANA (3 kg), the wool from 6.6 sheep would be required, and this would have a volume of $6.6 \times 0.007636 = 0.0504\ m^3$. The side of an equivalent square bale of the same volume would be the cube root of this volume $3\sqrt{0.0504} = 0.37$ m. A bale of this size and weighing 3 kg seems from an ergonomic point of view the ideal weight for one man to carry.[637]

This thesis will follow Killen's proposal that the average weight of wool per animal equals 0.75 kg and the unit of account for wool was the LANA, equal to the wool from four sheep. These values will be used as the input parameters into CLOTHCALC for the assessment of manpower requirements for spinning wool.

## 4.8.2 Number of shepherds and size of flocks required

It has been shown in Section 4.5.4 that the weight of fibre required to clothe 100,000 people would have been 105,110 kg, and it is assumed for this analysis that the weight of fibre required for wool is approximately the same as for flax. With the average yield of wool equal to 0.75 kg, and with 10.5% of this of no value for spinning, the resulting wool yield ready for spinning is 0.67 kg per animal.[638] The number of sheep required would therefore be $105,110 \div 0.67 = 156,881$ sheep. Estimates of the size of flocks in antiquity vary. The Knossian D tablets suggest that

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Knossian scribes were the double mina, designated M = 0.964 kg, the half mina, designated N = 0.241 kg, and the 1/24 mina, designated P = 0.021 kg.

[635] Melena 1987: 398-401.

[636] Ryder 1983: 708.

[637] For a full analysis, see Report 4.10c in CLOTHCALC. Melena 1975: 399 uses a different rationale and estimates that the side of a square bale of one LANA would be 0.47 m. In either case the bales could be easily carried by one man.

[638] Wiseman 1953: 98 translation of text ATT/8/183. See also earlier discussion Wiseman 1953:16.

flock sizes were in the range of 50-120, the variation being due to the mix of ewes, wethers and rams.[639]

It is obvious from this random selection of evidence that many factors influence the ratio of flock size to shepherd. The ratio in pastureland must be much higher than in flocks feeding on fallow land, as practiced in the Aegean. In the former situation the shepherd must have been very busy preventing the sheep and goats from moving onto arable strips. At different times of the year, more attention is also required by the shepherd than at other times, particularly in the lambing season.[640] A reasonable assumption for calculation purposes, based on the evidence above, is to use a flock size of 100 with each flock managed by a minimum on average of one shepherd. The number of flocks, assuming one shepherd per flock, would give 156,881 ÷ 100 = 1,569 shepherds.

## 4.8.3 Time taken to gather wool

### Washing sheep

The process of gathering wool started with the sheep being washed or more probably sent to the local river to remove dirt, impurities, and parasites. The suint, a phosphate-rich residue from sheep perspiration acted as a natural detergent.[641] To wash a sheep in running water probably required three people, one washing and two holding the sheep. It is unlikely that more than 12 sheep could be washed in this manner per hour. To wash 156,881 sheep would take 13,073 hours.[642] However, three workers were required to hold the sheep, so the total washing workload is three

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[639] Killen 1964: 9, footnote 49. See also Ventris and Chadwick 1973: 204 analysis of tablets Dk1070-1074 and Dl933, 938, 943, 946 and 947 (n=10) give an average of 110 sheep. Halstead's analysis of the Pylos Cn tables show that many flocks were segregated by wethers, ewes and old wethers with average sizes of 94, 57 and 116. Halstead 1990-1991: 356-357, particularly Table 5, which gives the flock populations, standard deviation and mean for each of the three groups. An Old Babylonian text shows that a shepherd was responsible for 158 sheep and 64 goats (Postgate 1992: 160). Koster, basing his argument on ethnographic evidence from the north-east of the Peloponnese, states that a flock size as low as 50 was common, with one shepherd.(Koster 1977: 277). Ethnographic evidence from Iran suggests flock sizes ranged from 60-100 (Barth 1964: 16 and 109).

[640] Large state or temple flocks probably provided a synergistic benefit through economies of scale whereby the employment of a number of shepherds could husband very large flocks, consequently improving the shepherd/sheep ratio.

[641] Melena 1975: 435. For a chemical overview of suint, see Stewart 1962: 907.

[642] See Report 4.10a.

times higher, giving 39,219 man-hours, which is equivalent to an utilised annual workload of 13 man-years (Report 4.10a).[643]

## Gathering wool

By convention, the removal of wool prior to the practice of shearing is known as plucking. The bulk of the wool was removed by using a comb rather than by hand plucking. Sheep were plucked of their wool in spring when they were moulting, as this minimised any discomfort for the sheep.[644] Gathering wool in this way conveniently left behind the coarser kemp and hair (vestiges of the primitive outer coat), which moults after the wool fibres.[645] Although the wool yield from plucking was lower than from shearing, the quality of the wool was higher, as it had a greater proportion of fine woollen fibres.[646] No bronze shears have been found in archaeological records, possibly due to the fact that the costs involved in making bronze shears outweighed any productivity benefits. Another suggestion is that, in order to shear effectively, the blades must have some form of springing action, and this was not possible until the introduction of iron shears in the Iron Age.[647] This springing action can be clearly seen in the design of ethnographic examples of hand shears and plucking combs (Figure 4.47). It is probable that wooden combs were also used to remove the wool, to supplement hand plucking. Combs have been found in archaeological records and ideograms Linear A 74 and Linear B sign *235 could possibly represent combs.[648]

No Mesopotamian or Mycenaean texts have been found that enable a direct computation of the number of man-days required to gather wool by plucking. Two texts will be used, together with ethnographic evidence, to make an estimate of the wool-gathering rate. The Alalakh tablet ATT/8/183 shows that a flock owned by Kipugga produced 8 talents, 1800 shekels of wool, gathered from 308 sheep. Of this

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643 Hereafter the assumptions of a working day of 9 hr day for 347 days per year will be used for all annualised workload calculations.
644 Ryder 1983: 49.
645 Wild 2002: 5.
646 Melena 1975: 403.
647 Forbes 1956:7.
648 Melena 1975: 414 and Figure 3. Ethnographic evidence attests to the widespread use of springy iron combs (Figure 4.48), which are used today for gathering wool from cashmere goats in underdeveloped regions (Melena 1975: 417).

weight, 10.5% of the wool yield was of no practical use (2700 shekels).[649] It also states that 1557 were plucked at one time, though the time taken and the number of gatherers are not stated. Melena argues convincingly that there is sufficient textual evidence to state that this operation was carried out over a short period of time. To gather wool, the weather must be dry and the operation must be carried out in the short moulting season. Restricting wool gathering to a short period reduces the risk of wool loss by the natural loss through moulting.[650]

The second text concerned requests made by the officer in charge of the flock for an increase in temporary manpower in order to gather the wool. This officer was named Mequibum, and the text states that he was in command of 150 skilled wool gatherers. To complete the work in three days, he required additional 300-400 workers, giving a total workforce of 450-550 workers to pluck.[651] Experimental archaeology shows that 20-30 animals can be processed per day.[652] Using these experimental rates and the assumption that the additional workers were used to restrain the animals during wool gathering, the total number of sheep processed would be in the 1,000-1,500/day. Despite the uncertainties of these assumptions, it would seem that these two examples of Kipugga and Mequibum show that a wool-gathering rate of 20-30 sheep/day is of the same order as the experimental archaeology evidence. CLOTHCALC has therefore used a wool-gathering rate of 25 animals/day, with one skilled worker supported by two supplementary workers.

### Manpower requirements

The utilised annual workload for plucking wool would be in total 55 man-years (Reports 4.10a in CLOTHCALC).

## 4.8.4 Combing wool

The final process involved in preparing wool for spinning was removing the natural tangles and waves in the wool fibres. Combing is not the same as the use of a comb

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[649] See again Wiseman 1953: 16, 98 translation of text ATT/8/183. The 10.5% loss is calculated using a shekel to the talent of 3000 to 1.
[650] Melena 1975: 428-434.
[651] *CAD, s.v. baqāmu,* 97 following. Full textual references given in Melena 1975: 428-434.
[652] I am grateful for this information from Dr E. Arnott, experimental archaeologist at Fishbourne Roman Palace, Fishbourne, West Sussex, UK for sharing her expertise in the preparation of wool, drop spinning, weaving and dyeing in Bronze Age, Iron Age and Roman Britain.

in the plucking of wool, as described above, and the nearest equivalent process in flax preparation is hacking, described in Section 4.7.1 above. From these the bundles of combed wool fibre called roves or rolags are spun into threads.[653] Melena suggests the majority of combs for plucking were probably cheap, and made from wood.[654] To fill this gap in archaeological records, Barber carried out an etymological study to look for evidence of this process.[655] Her findings indicate that combing rather than carding was the standard practice in antiquity to prepare wool for spinning. Combing creates parallel fibres, which when spun produce strong yarns similar to modern worsteds. Carding, makes the fibres lie in many directions, giving a fluffy feel to the rove, which, when spun, produces softer but weaker yarn.[656]

### Time taken to comb the wool from one sheep

No published information on the time taken to comb wool was forthcoming, and again the author is grateful to Suzanne Evans, Senior Education Officer and experimental archaeologist Dr E. Arnott, from the Roman Fishbourne Palace museum. Their replication experiments involving carding the wool using traditional methods rather than combing it took approximately 10-15 hours. Two adjustments have to be made to adjust this figure back to LBA conditions, that is, compensate for the weight of a modern fleece, and the productivity gain of using traditional carding methods compared with combing. A modern-day downland sheep has a higher wool yield (2 kg wool only from the fleece), so the time must be first prorated down to 0.75 kg from a typical LBA sheep. The efficiency of combing compared to carding can only be estimated, but it is reasonable to assume that 130% more effort would be required to take into account the slower process. Combining these two factors reduces the time taken to comb the wool from a sheep compared with traditional

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[653] Barber 1991: 184, citing Schlabow 1974: 193. Barber 1991: 261-262.

[654] Melena 1975: 415 footnote 103. Very few combs have been found in antiquity, though one bronze comb was found in Grave Circle B at Mycenae, and another, from ca. 1300-1100 B.C. was made from horn and found in a bog near Schwarza in South Thuringia. Alalakh text ATT/8/16, 30 wooden combs were included in a list of wooden objects that could possibly have been used for wool combing.(Wiseman 1953: 108 translation of text ATT/8/16).

[655] Barber 1991: 260-282 studies the whole wool production process, but combing and carding are covered in pages 261-262. There is textual evidence that combing was used to remove wool from the live sheep when moulting, which produced better fibre than plucking (Barber 1991: 260-261, citing Hallo 1979: 4-7 study of UR III texts).

[656] In modern craft production, hand carding is performed using two pairs of wooden paddles with wire teeth, and placing wool on one paddle and pulling the other across it a number of times produces the fluffy woollen rove.

carding of fleece wool from 15 hrs to 7.4 hours. The number of days required to comb the wool gathered from the sheep equals the number of sheep × combing rate of hrs/sheep ÷ available hours worked per day say 9 hrs/day = 129,000 days. The resulting utilised annual workload for combing 156,881 sheep required to produce sufficient cloth to clothe 100,000 people would have been 372 man-years.[657]

In summary, the total annualised workload to prepare the wool for spinning is the sum of washing; plucking, and combing workloads would be 440 man-years.

| Preparation of woolen fibre for spinning | |
|---|---|
| Washing sheep | 13 |
| Plucking wool off the sheep | 55 |
| Combing the wool for spinning | 372 |
| **Total man-years** | **440** |

**Table 4.23: Total man-years to prepare sufficient wool for spinning to provide enough yarn to clothe 100,000 individuals**

[657] For the full analysis see Report 4.10a in CLOTHCALC.

# 4.9 Spinning

Spinning with wool or flax remained a production bottleneck until the Industrial Revolution, and this section will show that spinning took 287% more workers in than weaving in Egypt. In this culture, where linen predominated over wool in the LBA, a different process was followed, which involved splicing the flax fibres, in contrast to other Eastern Mediterranean regions, where the flax and wool fibres were spun using drop spindles. The splicing process used by the Egyptians will be examined first, followed by the artefacts used in spinning, and an estimate is made of the length of yarn required to make sufficient cloth to clothe 100,000 people, and the manpower involved to produce this cloth.

## 4.9.1 Splicing flax fibre

The purpose of spinning is to produce a single cohesive length of slightly elastic fibres. In New Kingdom Egypt, spindle yarn production in antiquity was a two-stage process. The first stage involved splicing flax fibre into one or more loose twisted threads. It should be noted that if wool is being spun, the revolving spindle draws out small quantities of wool fibre and is attenuated and aligned into a drafting triangle with the spindle, imposing a twist up the length of the thread, as shown in Figure 4.49.[658] This was achieved by taking two fine fibres at a time, overlapping them by up to 0.05-0.08 m, and splicing them by rolling them on the thigh (Figure 4.50).[659] A third fibre is simultaneously rolled with the other two spliced fibres, but offset from the first, and this is then in turn spiced to another fibre, and so on. This process ensures that no two given spliced joints occur in parallel within the thread, thus improving the strength and quality of the cloth. Splicing sounds more complicated than it is, but the process is made clearer by Figure 4.51. A splice flax joint magnified x18 is shown in Figure 4.52.[660]

Linen fibres can be spun by thigh spinning of a spindle. Tiedemann and Jakes' study into Prehistoric spinning technology examined ethnographic and experimental

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[658] (Tiedemann and Jakes 2006: 294). Egypt's splicing method was probably unique in the Eastern Mediterranean. Most Near Eastern cultures used draft spinning for all fibre spinning, irrespective whether the source was flax, wool or goat hair (Barber 1991: 42-44).
[659] Barber 1991: 45, Figure 2.5.
[660] Jones 2006: Plate 59e.

archaeology evidence to compare the relative efficiencies of thigh spinning and spindle spinning.[661] Although thigh spinning of bast fibre is not exactly analogous to splicing flax fibre, as performed by the Egyptians, the ergonomics of the two are not dissimilar. As there is a lack of published experimental archaeology, this thesis has assumed that the time taken for thigh spinning was comparable to splicing. The average of three measurements of thigh spinners, spinning flax was 0.129 m/min or more useful for this study 7.75 mins/m.[662] However, the length of the splice was on average 5-8 cms (average 0.065 m on an average bast fibre length of 0.9 m), so the length spun would be approximately 7.2% of the length of a typical bast fibre. Adjusting the time taken to spin one metre of spliced thread would be 7.2% of the time taken for thigh spinning flax that would result in a rate of 0.558 min/m.[663]

The splicing process is repeated ad infinitum with the resulting loose-twisted thread rolled into a ball or coils, as shown in the tomb of Thutnefer (Figure 4.53). Sometimes the thread is seen passing through the lips of the spinner as the enzymes in the saliva react with the plant cellulose that helps bind the fibres together, making the bast fibres easier to control and manipulate when wet (Figures 4.54).[664] Ethnographic evidence of this practice can be found in Crowfoot's observations on the final stages of spinning in villages in Upper Egypt and Sudan in the 1920s. (Figure 4.55).[665] Barber suggests that bowls with internal loops, which were found across the Eastern Mediterranean in the LBA, had two functions. The loop provided tension to the balls of wool or spliced flax threads when spinning, and if water was placed in the pot when spinning flax thread, it would wet the threads (Figure 4.56).[666]

### 4.9.2 The spinning process and the artefacts used

Up to the time of the New Kingdom, Egypt was conservative in its attitude to change and the adoption of new technologies.[667] Awareness of new technologies would have

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661 Tiedemann and Jakes 2006: 293-307.
662 Tiedemann and Jakes 2006: 300, table 2.
663 Report 4.11c in CLOTHCALC.
664 Barber 1991: 72.
665 Crowfoot 1931: 34.
666 Barber 1991: 73 and Dothan 1963: 97-112, particularly Figures 1 and 3.
667 Moorey 2001: 6-12. The Egyptian system would adapt to technological changes if quality could be enhanced, but was less inclined to change for increases in productivity. It is suggested that this is due to its geographical isolation up to the end of the Middle Kingdom, as well as the fact that it was almost self-sufficient in terms of raw materials and food. This situation started to change following

accelerated in the Nineteenth dynasty as Egypt's hegemony spread north and south of its borders. It is surprising then that draft spinning of flax (see again Figure 4.49), which was a well-established practice outside Egypt, was not introduced until the Late Period or even the Hellenistic period, particularly since draft spinning of wool was the norm from the Eighteenth Dynasty on.[668]

Many different designs of whorl were used to spin the yarn in antiquity, but they all operate in the same manner. The most common design in Ancient Egypt is shown in Figure 4.57. Its purpose was to reduce hand movements when twisting the fibres into a thread, and it achieves this by exploiting the angular momentum stored up in the mass of the annular ring of the spindle, which in turn maintains the rotational movement of the spindle.[669] The other purpose of this design was to provide a store for the spun fibre. The spinner applies a torque to the spindle in a similar manner to a child setting a spinning top in motion. The weight and thickness of thread produced is a function of the weight of the whorl, and the tightness of the thread is a function of the diameter of the whorl to its weight. Generally the heavier and larger whorls produced thicker thread, and lighter whorls were used to produce light but tight threads.[670] The convention is to define yarn as s-spun if spun in an anti-clockwise direction and z-spun in a clockwise direction (hereafter called s and z threads).[671] Examples of different combinations are shown diagrammatically in Figures 4.58a-4.58c.[672]

The proportion of the number of single threads to threads of two-ply or greater does vary from textile to textile.[673] A study of 3625 pieces of woven linen cloth found in the workmen's village at Amarna show that 78% of the samples were two-ply.[674]

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the invasion of the Hyksos in the Second Intermediate period, which stimulated an increase in the mobility of artisans and brought in new technological practices.

[668] Kemp and Vogelsang-Eastwood 2001: 88.

[669] The annular rings can be made of wood or of limestone, travertine or clay (Vogelsang-Eastwood 2000: 272). For a Eastern Mediterranean-wide view of spindle and whorl design and its survival in archaeological records, see the thorough review of Barber 1991: 51-68.

[670] Smith 2007: 229.

[671] Hereafter yarn will be used to mean two or more twisted threads, and two threads plied together will be referred to as two-ply.

[672] For the most common combinations found in Amarna for threads, strings and cords, see Eastwood 1985: 192-194; Table 10.1 and Kemp and Vogelsang-Eastwood 2001: 59, Figure 3.1.

[673] For mummy wrappings, see Midgley 1978: 26-29, for Amarna see Eastwood 1985: 191-204.

[674] Kemp and Vogelsang-Eastwood 2001: 58-60, Table 3.3. Hereafter single threads will be called singles and two threads plied together will be referred to as two-ply.

Woollen textiles predominantly used single-ply yarn for weaving of cloth, but neo-Sumerian records of the UR III period show that two-ply was generally only found in first to third-class cloth.[675] It was also used when strength was important or if a two-colour effect was desired, using a thread of black and white wool.[676] Crowfoot proposes that the reason behind the use of two-ply in flax was to improve quality by making the yarn stronger for weaving.[677] To know the proportion used is important because this influences the time taken to spin the fibre for a given area of finished cloth.

### Time taken to produce two-ply flax yarn

Production of two-ply takes three spinning operations; two singles and one plying of the two singles to make two-ply. So for each single metre of two-ply thread to be made, two threads of one metre have to be spliced, and then plied together to make one metre of two-ply yarn. The average plying rate min/m for two-ply is given in the relationship below.[678]

$$R_{two\text{-}ply} = R_s + R_s + R_p$$

Using the formulae above, the time taken to spin one metre of $R_{two\text{-}ply}$ yarn would have been 1.616 mins/m, where:

$R_s$ is the number of minutes to splice 1 m of singles (evaluated in Section 4.7 above) = 0.558 mins/m.

$R_p$ is the number of minutes to ply two spliced singles into 1 m of yarn = 0.5 mins/m.[679]

## 4.9.3 Area of yarn required to clothe 100,000 people

To calculate the total time required to spin sufficient yarn to produce the amortised requirement of cloth to clothe 100,000 people (see Section 4.4.4), some assumptions must be made on the quality of cloth used across different socio-economic groups.

[675] Waetzoldt 1972: 122-123 translations of relevant texts with full textual references in footnotes 373-384. For discussion on quality classifications of linen and woollen cloth, see Section 4.10 following.
[676] Waetzoldt 1972: 123 translation of text Šurpu V/VI 150f.
[677] Crowfoot 1954: 431-436.
[678] Tiedemann and Jakes 2006: 300-301.
[679] Tiedemann and Jakes 2006: 303 citing the experimental archaeology study by Vallinheimo 1956.

Kemp and Volgelsang-Eastwood's measured 4,963 textile fragments found in the workmen's village at Amarna.[680] The diameters of 3,385 of these was measured and recorded in the Kemp database. The following convention has been used throughout this thesis. Diameter range 1: very fine (less than 0.2 mm); 2: fine (0.2-0.3 mm); 3: medium (0.4-0.6 mm); 4: coarse (0.6-0.9 mm); 5: very coarse (greater than 0.9 mm). This thesis uses the assumption that the area of cloth woven using these five types of yarn is proportional to the number found within each category, and this has been collated in the AMARNA DIAMETERS spreadsheet and the results shown in table below[681].

| Range yarn diameters mm (n=3,385) | Average yarn diam. mm | % |
|---|---|---|
| 0-0.2 | 0.15 | 14.9 |
| 0.2-0.3 | 0.25 | 71 |
| 0.4-0.6 | 0.5 | 12.9 |
| 0.6-0.9 | 0.75 | 1 |
| Greater Than 0.9 | 1 | 0.2 |
| | | 100 |

**Table 4.24: Yarn diameters measured from 3385 cloth samples found in the workmen's village at Amarna. Data source Kemp 2001.**

This thesis also makes the assumption that the above yarns from the workmen's Village are most applicable to socio-economic groups 4.[682] The research carried out by Vogelsang-Eastwood and others indicate that the higher the social status, the finer the cloth that was used to make up garments. Conversely, it is reasonable to assume that farm workers would wear the coarsest cloth. This means that the percentages of yarn diameters used to make a range of cloth for socio-economic groups 1-3 must be skewed to reflect smaller yarns, and similarly the percentages of yarn diameters used to make a range of cloth for socio-economic group 5 must be skewed to reflect larger coarser yarns. The percentages for the five socio-economic groups used in this analysis are given in the table below.

[680] The base data has generously been made public in a databank available from Kemp 2001. The base data has been copied into an Excel spreadsheet named AMARNA, and is used for correlation and statistical analysis in this thesis (see Volume 3).
[681] For all calculations the averages of each diameter range are used.
[682] Socio-economic group 4 is assumed to be made up of senior professionals, priests, army officers, scribes, and mayors. Socio-economic group 4 is assumed to be composed of lower professionals, skilled craftsmen and small landowners.

| Socio-economic groupings | Percentage distribution of yarn diameters mm | | | | | Total | Area of cloth m² |
|---|---|---|---|---|---|---|---|
| | 0.15 | 0.25 | 0.5 | 0.75 | 1 | | |
| Socio-economic groups 1 | 35 | 55 | 9 | 1 | - | 100 | 1,502 |
| Socio-economic groups 2 | 29 | 60 | 10 | 1 | - | 100 | 1,775 |
| Socio-economic groups 3 | 16 | 72 | 11 | 1 | - | 100 | 10,675 |
| Socio-economic groups 4 | 14.9 | 71 | 12.9 | 1 | 0.2 | 100 | 49,840 |
| Socio-economic group 5 | - | 10 | 30 | 45 | 15 | 100 | 154,781 |
| | | | | | | | 218,573 |

**Table 4.25: Percentages of the area of cloth required for the range of socio-economic groups, studied by the yarn diameter used in production**

Using these percentages, the area of cloth made from the range of yarn diameters can be prorated for each of the socio-economic groupings. For example, for socio-economic group 4, the area of cloth made from 0.25 average diameter would be 71% of the area of cloth for the whole of socio-economic group 4 (49,840 m$^2$), giving the result 35,386 m$^2$.[683] A summary of all the results is given in the table below and the full analysis is provided in Module 6 in CLOTHCALC.

| Socio-economic groupings | Egypt | | | | | |
|---|---|---|---|---|---|---|
| | Area of cloth collated by average yarn diameter mm. | | | | | Area of cloth m² |
| | 0.15 | 0.25 | 0.5 | 0.75 | 1 | |
| Socio-economic groups 1 | 526 | 826 | 135 | 15 | - | 1,502 |
| Socio-economic groups 2 | 515 | 1,065 | 178 | 18 | - | 1,776 |
| Socio-economic groups 3 | 1,708 | 7,686 | 1,174 | 107 | - | 10,675 |
| Socio-economic groups 4 | 7,426 | 35,386 | 6,429 | 498 | 100 | 49,840 |
| Socio-economic group 5 | - | 15,478 | 46,434 | 69,651 | 23,217 | 154,780 |
| Totals | 10,175 | 60,441 | 54,350 | 70,289 | 23,317 | 218,573 |

**Table 4.26: Area of cloth required collated by socio-economic group and yarn diameters**

## Length of yarn to make the cloth required to clothe 100,000 people

Having collated the total cloth requirement for each socio-economic group by yarn diameters, this data can now be used to calculate the length of yarn required for production. As woven cloth shrinks when taken off the loom, allowances must be made when calculating the length of yarn required. During the weaving process, the weft goes over and under the warps, drawing them closer together. This is called the take-up and could be as much as 10% in the weft and 8% in the warp. In addition, as with all cloth, when it is washed, natural shrinkage occurs. For flax this is typically 6% in the weft and 8% in the warp. To produce, for example, a finished piece of cloth of one square metre, the weft on the loom must be set to a length of 1.16 m and

[683] For Cyprus see Report 4.6f.

the warp would also be 1.16 m. To this 0.8 m must be added for tying off each warp, making a total warp length of 1.96m.[684]

The total length of yarn required also depends on the number of wefts/m and warps/m for each of the yarn diameters making up the cloth. Of the 4,963 fabric samples in the Kemp 2001 database, 2,584 samples have a diameter measurement and an estimate of the warp and weft counts (Figure 4.59). These were analysed in the AMARNA spreadsheet by collating warp and weft counts against diameter categories. The distributions are not normal, so the median is used rather than a simple average. The results are summarised in the table below.

| Av. yarn diam mm (n=2,582) | Median warps/m | Median wefts/m |
|---|---|---|
| 0.15 | 2,940 | 1,690 |
| 0.25 | 2,260 | 1,230 |
| 0.5 | 1,760 | 950 |
| 0.8 | 1,010 | 810 |
| 1 | 800 | 500 |

**Table 4.27: Average warp and weft counts in 2582 samples collated by yarn diameter**

Knowing the median of the wefts/m and warps/m, and multiplying them by the lengths of a single weft and warp identified above (1.16m and 1.96 m respectively), the total length of yarn required to make one m$^2$ of cloth can be calculated. For example, for cloth using yarn of average diameter 0.15 mm, the average values for the weft and warp counts were 2,940/m and 1,690/m respectively. The length of yarn therefore would be (1,690 × 1.16) + (2,940 × 1.96) = 7,722 m. For the full range of yarn diameter categories, see the table below.

| Average diameter of yarns mm | 0.15 | 0.25 | 0.5 | 0.75 | 1 | mm |
|---|---|---|---|---|---|---|
| Av. warp count/m of 2,582 Amarna samples | 2,940 | 2,260 | 1,760 | 1,010 | 800 | per m |
| Av. weft count/m of 2,582 Amarna samples | 1,690 | 1,230 | 950 | 810 | 500 | per m |
| Length of weft thread to make 1 sq m of cloth | 1,960 | 1,427 | 1,102 | 940 | 580 | m |
| Length of warp thread to make 1 sq m of cloth | 5,762 | 4,430 | 3,450 | 1,980 | 1,568 | m |
| **Tot. length of yarn required to make 1 m$^2$** | 7,722 | **5,857** | **4,552** | **2,920** | **2,148** | **m** |

**Table 4.28: Total length of yarn required to make 1 m$^2$ of cloth using different yarn diameters**

684 Petrini 2006. Note that Petrini's analysis this does not refer to the contraction of a fibre, yarn or fabric after washing and drying. All products made of natural fibres have a tendency to shrink an additional 4%-8% as included in CLOTHCALC.

## Total length of yarn required for different socio-economic groups

Multiplying the results of Table 4.26 (area of cloth/m$^2$ collated by yarn diameter) by the total length of yarn to make one m$^2$ of cloth (Table 4.28) enables the calculation of the total length of yarn required for all socio-economic groups. Taking as an example cloth made with yarn of diameter 0.15 mm, the area of cloth required for socio-economic group 4 was 7,426 m$^2$ (see again Table 4.26). The length of two-ply yarn required per m$^2$ of cloth using the yarn of 0.15 mm average diameter from Table 4.28 equals 7,722 m. Multiplying one by the other and dividing by 1000 to convert to km, the total length of yarn required for socio-economic group 4 using diameter 0.15 mm would be equal to 57,344 km. A summary for all cases is given in the table below.[685]

| **Total length km of yarn required for Egypt collated by socio-economic groups** | | | | | |
|---|---|---|---|---|---|
| **Yarn diams mm categories 1-5** | **0.15** | **0.25** | **0.5** | **0.75** | **1** |
| Socio-economic groups 1 | 4,062 | 4,838 | 615 | 44 | - |
| Socio-economic groups 2 | 3,977 | 6,238 | 810 | 53 | - |
| Socio-economic groups 3 | 13,189 | 45,017 | 5,344 | 312 | - |
| Socio-economic groups 4 | 57,344 | 207,256 | 29,265 | 1,454 | 215 |
| Socio-economic group 5 | - | 90,655 | 211,368 | 203,381 | 49,870 |
| **Total length of yarn km** | **78,572** | **354,004** | **247,402** | **205,244** | **50,085** |
| | | **Egypt - total length (km)** | | | **935,307** |

| **Total length km of yarn required for Cyprus collated by socio-economic groups** | | | | | |
|---|---|---|---|---|---|
| **Yarn diams mm categories 1-5** | **0.15** | **0.25** | **0.5** | **0.75** | **1** |
| Socio-economic groups 1 | 4,278 | 5,096 | 646 | 47 | - |
| Socio-economic groups 2 | 4,193 | 6,577 | 851 | 55 | - |
| Socio-economic groups 3 | 14,000 | 47,781 | 5,672 | 330 | - |
| Socio-economic groups 4 | 59,977 | 216,762 | 30,608 | 1,521 | 223 |
| Socio-economic group 5 | - | 95,944 | 223,703 | 215,251 | 52,781 |
| **Total length of yarn km** | **82,448** | **372,160** | **261,480** | **217,204** | **53,004** |
| | | **Cyprus- total length (km)** | | | **986,296** |

**Table 4.29: Length of yarn m required to meet the demand for cloth**

[685] The full analysis for Cyprus is given in Report 4.6h.

# 4.10 Weaving

## 4.10.1 Looms and associated equipment

Egyptian tomb paintings show the weaving process in great detail (Figure 4.60). Middle Kingdom models provide a three-dimensional portrayal of the spinning and weaving process (Figure 4.61). Archaeological records add to our knowledge of loom development from the survival of fragments of looms, weights and their associated tools.[686] The archaeological evidence indicates the horizontal-linked two-beam ground loom has been in common use in the Middle East and Egypt from the Neolithic to the present day.

By ca. 1480 B.C. fixed two-beam vertical looms had been introduced into Egypt with the increased industrialisation of weaving (see again Figure 4.7). From the New Kingdom in Egypt onwards, vertical looms were mainly operated by men and horizontal looms by women.[687] No loom parts, with the exception of loom weights, have been found in Aegean LBA contexts. However, the Linear B ideogram *159 meaning cloth is frequently found in the K, N and L series of texts, and the word *pa-we-a* = woollen cloth is frequently found associated with this ideogram. The ideogram itself represents a vertical loom of similar design to that portrayed in the Egyptian tomb paintings (Figure 4.62). Vertical lines may represent warp threads and horizontal lines weft threads, and these vary in number, possibly representing different type of weaves.[688] The small lines extending below the loom are thought to represent loom weights.[689]

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[686] For evidence of loom weights and spinning whorls from the Aegean and particularly Thera, see Tzachili 1990: 380-389. For evidence of loom parts found in caves in the Dead Sea Region of Israel, see Bar-Adon and Pommerantz 1980: 179-181. For Egyptian finds from Gurob (see Petrie 1917: 133-136. Plate 66; Thomas 1981: Plate 45 no. 98, Plate 5 no. 99) and Amarna (Peet *et al* 1923: Plates 20.3). Heddle jacks from Kahun can be found in the Petrie museum (Petrie, Griffith and Newberry 1890: Plate 9, no. 12; Barber 1991: 85, Figure 3.7) and Manchester Museum, Acc. No. 50. Egyptian weft-thread beaters, wooden combs, spools and shuttles attached are to be found in the care of Leiden Museum collection (Leiden, RMO AJ147a, Vogelsang-Eastwood 1994: Figure 43). A wooden lathe found in Kahun similar to that shown in the tomb painting of Khnumhotep was a laze rod (Roth 1913: 19, Figure 20). Barber 1991: 85-90 and Vogelsang-Eastwood 2000: 276-278 gives a modern interpretation of these finds and compare them with Egyptian tomb paintings and tomb models.

[687] Lloyd 1976: 148.

[688] Palmer 1963: 290.

[689] Ventris and Chadwick 1973: 313.

Bellinger has suggested that vertical looms produced a cloth that was close-set, with evenly-spaced warp yarns with an absence of a fringe on the left side. She suggests that the characteristic of cloth made on a horizontal loom is for the web to be beaten in tighter on the left than the right, due to differential force created between the puller of the sword on the left and the pusher on the right. To ensure the two ends of the web remain in line, a fringe was added as a form of padding to the left salvage. This problem was eliminated with the vertical loom, as both weavers pushed the sword down from above with equal force.[690]

From the archaeological evidence, replicas have been built and tested, providing greater understanding of weaving practices in the LBA. These experimental archaeology studies supplemented with ethnographic evidence have enabled the reconstruction of the whole cloth production process to evaluate production times for different raw materials. Replicas of looms and tools from archaeological contexts have been tested for their function and suitability for reproducing particular types of textiles[691].

## 4.10.2 Warping the looms

Warping was a time-consuming task, and it took three women three days to warp looms to produce a cloth 3.5m x 3.5 m, according to an UR III text.[692] The Amarna textiles show that the warp count increased towards the selvedge, presumably to increase the cloth strength at this vulnerable edge.[693] The Egyptian horizontal loom could produce bolts of ca. 0.5m width (one cubit) of cloth, while the vertical loom could produce ca. 1.5 m width (three cubits) of cloth. The more 'industrial' vertical loom could produce standard cloth widths up to 5 m long.[694] By far the commonest

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[690] Bellinger 1959: 3-4.

[691] Andersson and Nosch 2003: 197-208, Barber 1991: 24; 289-98; 325-326; 370 and Peacock 2001: 181-192 with full bibliographic references. Tiedemann and Jakes' 2006: 295-307 replication studies of spindle-spun yarns present a detailed study of how fibre characteristics, fibre preparation and spinning techniques influence production rates.

[692] Waetzoldt 1972: 129 translation of text ITT V 9996 (T.32) Rs I 1-3.

[693] Kemp and Vogelsang-Eastwood 2001: 108-109. There is a natural tendency for this to occur as weaving progresses, but the fabrics examined at Amarna indicate that warp count density near the selvage was a deliberate decision made when setting up. The natural tendency for warp threads to bunch at the edges of the loom can be minimised using a tensioning device, or by the skill of the weaver in carefully beating down after each shuttle operation. There is no evidence in iconographic or archaeological records to show that such devices were used in Egyptian looms.

[694] Eyre 1998: 179, n31.

width of cloth used for garments, from the evidence of Egypt, the Aegean and Mesopotamia, is approximately 1-1.5 metres. This appears to be the ergonomic optimum for single operation of the shuttle on vertical looms and operation by two people on horizontal looms.[695] Wide looms are known in the Ancient Near East, but these were the exception rather than the rule for common clothing. One UR III text states a fabric was produced with dimensions 3.5 x 3.5m. In discussion with the Irish Linen Centre & Lisburn Museum regarding linen-weaving rates (see following section), it is probable that the 3.5 m cloth was made up of perhaps three sections approximately 1.15 m wide.[696] This is a view shared by Petzel.[697] Ethnographic evidence from Hebron shows that weaving up to 3 m width is physically possible using three weavers, as shown by the weavers from Hebron (Figure 4.63).[698] For this analysis, a loom of one metre in width and two metres in length has therefore been assumed, producing two $m^2$ of cloth before re-warping. This means that to produce an area of cloth to clothe 100,000 people (218,573 $m^2$), the looms would require warping 109,287 times, with each warping operation taking one day. The full time equivalent number of weavers required would be 315.[699] It has also been suggested that, to ease weaving, the warp and wefts may have been oiled with olive oil to facilitate the smooth movement of the shuttle.[700]

## 4.10.3 Weaving rates in antiquity

It is assumed that the weaving rates for flax and wool were the same, as the looms would have been identical, and the physical sequence of operations remains the same irrespective of the fibre used. Weaving rates were a function of the size of the loom, the quality of the fibre woven and the weft count. The greater the weft count, the greater the workload, not just because the number of shuttle operations per unit length increases, but also because as the weft count increases, more time is spent

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[695] See earlier discussion on the area of cloth required to make the most common designs of clothing in Section 4.4.2.
[696] Waetzoldt 1972: 129 translation of UR III text ITT V 9996 (T.32) Rs I 1-3. The author is grateful for the helpful advice and sharing of information by the staff of the Irish Linen Centre & Lisburn Museum.
[697] Petzel 1987: 22.
[698] Schick 1998, Plate 3.12.
[699] For the analysis in CLOTHCALC see Report 4.12a.
[700] Warnock 2007: 3.

beating down.[701] UR III Text ITT V 9996 (T.32) points out that in one day three women could weave 0.25 m of third class ni-lam cloth or 0.333 m of fourth class ni-lam cloth. Guz-za cloth, also fourth class, could be woven by two women at a rate of 0.5m per day.[702]

It is necessary to make some assumptions regarding the quality of cloth expected by each socio-economic group. For reasons given above, assumptions made are biased towards Egyptian evidence. This evidence is taken as representative because other Eastern Mediterranean regions had similar socio-economic hierarchies and the basic technology of cloth production was the same. For socio-economic groups 2 (high elite) and 3 (senior officials), second-class cloth is assumed for clothing.[703] No textual data is available for the weaving rates of first or second-class cloth, but the finest cloth would probably have been available to Royalty or nobility only and will not be considered in this analysis.[704] The rationale used to estimate weaving times for second-class cloth is the time taken to weave any cloth is approximately a linear relationship to the weft count.[705] The weft and warp counts/m analysed from the Amarna data suggest that second-class cloth used fine yarn made from cloth of the order 3000 wefts/m and 2000 warps/m. Third-class cloth is estimated to have had 2000 wefts/m and 1200 warps/m, and the coarsest fourth-class cloth would have been of the order of 1000 wefts/m by 800 warps/m.[706] If fourth-class cloth was produced

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[701] Kemp and Vogelsang-Eastwood 2001: 108. See Section 4.5.1 for classifications of quality of fibre for weaving.

[702] Waetzoldt 1972: 138-139. As discussed earlier, the archaeological evidence suggests that most looms were designed to produce cloth of around one cubit in width. Allowing for shrinkage, a width of 1.15m is assumed, which would produce a finished cloth of approximately one metre in width. This ergonomically allowed the shuttle operator to send the shuttle through the warps in one action. In this analysis, it is assumed that the finished cloth was one metre wide and the area of cloth in these examples would be 0.25, 0.333 and 0.5 $m^2$ respectively. How guz-za cloth differs from ni-lam cloth is not clear, as they were both designated as fourth-class cloth. They were probably so named to reflect different quality characteristics of the spun yarn. It is known that (sag-) us-bar cloth was made from yarns that were coarse and uneven with many impurities, and that this was given to workers as part of their rations.(Waetzoldt 1972: 50-51).

[703] Definitions for socio-economic groupings are given in Section 4.4.1 above.

[704] This category of cloth could be considered as one of the options for rhe elite to allocate resources from the surplus manpower reserved for conspicuous consumption needs.

[705] If weft counts are increased, warp counts have to be increased, but not necessarily proportionally. The time taken for weaving is generally proportional to the number of times the shuttle is passed through the warps, and it follows that the greater the wefts, the more time is taken to make a given length of cloth. Warping time would increase but would still remain a small proportion of the total time taken to weave a finished cloth (see discussion in Section 4.10).

[706] Kemp and Vogelsang-Eastwood 2001: 100, Figure 4.11.

at a rate of 0.5 m per day and third class 0.333 m/day, then an estimate of 0.08 m/day for second-class cloth would seem reasonable.[707]

Other data on weaving rates in antiquity, which would be helpful to provide checks and comparisons, are very limited. A third-century B.C. papyrus from Roman Philadelphia (Egypt) states that three men and one woman assistant were required for six days to weave a single linen sheet, which represents 24 man-days of effort.[708] Unfortunately the size of cloth is not recorded. More convincing support comes from the weaving rates obtained from experimental archaeology which has replicated primitive looms and weaving processes. Danish experimental archaeologists have produced a copy of a woollen Iron Age blanket recovered from Vegan in South Jutland. Although made on an Iron Age warp-weighted loom, the basic functional design follows those used in the LBA, and indeed the basic operation and design of loom-weighted looms can still be found today in rural areas of the Near East. The results are therefore considered to be of the same order as the looms used in the LBA. Using a warp-weighted loom, a rectangular woollen twill cloth 2 x 1.5 m wide was woven in 292 hours.[709] Assuming an eight-hour working day for women in antiquity, this would have represented 36 man-days of effort. Converting this to a manpower rate/$m^2$ would give 12 man-days/ $m^2$ of cloth woven, which is of the same order as the weaving rates expected to make third-class cloth in the UR III texts of nine man days/$m^2$ of cloth woven. The twill cloth produced was substantial, warm and of a quality that would be expected to be worn by socio-economic group 4, who were not, part of the elite but had a higher status than people working on the land.[710]

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[707] Difference between average weaving rates for fourth-class and third-class cloth = 0.333 - 0.25 = 0.083 m/day. Extrapolating for second-class cloth, assuming a linear relationship between weft count and weaving time, would give a weaving rate of 0.25 – 0.083 = 0.167 m/day.

[708] PSI VI, 599 cited by Wild 2002: 31.

[709] Nørgaard and Östergaard 1994: 17-19.

[710] The weight of the experimental cloth was 13.6 kg, very close to that prescribed for a blanket measuring 2.66 m by 1.78 m, as supplied to legions and auxiliaries in second-century Roman Egypt (Wild 2002: 31). A blanket of the size and weight of the Roman example would be expected to have been made in the same time, as loom design had not changed significantly since the Bronze Age. If Roman society was classified in terms of the socio-economic groups used in this thesis, then the soldiers would belong to socio-economic group 4. Putting these two pieces of information together provides indirect, if not strong, evidence that the UR III data is a good indicator of the weaving time required to produce third class cloth.

In summary, for socio-economic groups 1 and 2, second-class cloth is assumed, with a weaving rate of 0.08 $m^2$/day. For other socio-economic groups see the table below.[711]

| Class of cloth | Width of finished cloth m | Area of cloth woven $m^2$ /day |
|---|---|---|
| Second class cloth | 1 | **0.08** |
| Third class cloth | 1 | 0.25 |
| Fourth class cloth | 1 | 0.333 |
| Ration quality 4th class cloth | 1 | 0.5 |

**Table 4.30: Area of cloth woven per day collated by class of cloth**

## 4.10.4 Manpower required to weave total cloth requirement

It is now possible to calculate the number of workers required weaving sufficient cloth to clothe a representative sample population of 100,000, and the calculation will be presented in stages. The input data and assumptions required for each stage have been discussed previously. The analysis will take into account two factors; the demographic split of the population by socio-economic group, and the quality of cloth expected to be used by each socio-economic group.

### Area of cloth collated by socio-economic group and cloth quality

The areas of cloth required by the different socio-economic groups and the quality of cloth have previously been collated in CLOTHCALC in Report and discussed in Section 4.4.5. This has been further collated by allocating cloth quality to socio-economic groups, as discussed in the summary of Section 4.10.1. The collated results are shown in the table below.

| Area of cloth | Socio-economic groups | Popul'n | Egypt area of cloth $m^2$ | Cyprus area of cloth $m^2$ |
|---|---|---|---|---|
| Area of second class cloth | 1 & 2 | 440 | 1,502 | 3,453 |
| Area of third class cloth | 3 | 2,530 | 12,450 | 11,330 |
| Area of fourth class cloth | 4 | 10,000 | 49,840 | 52,125 |
| Area of ration quality fourth class cloth | 5 | 87,030 | 154,781 | 163,813 |
| **Total** | | **100,000** | **218,573** | **230,721** |

**Table 4.31: Area of cloth required to clothe 100,000 people, collated by cloth quality**

[711] Source data collated from Reports 4.12a-4.12e CLOTHCALC.

## Number of days to weave one m² of cloth

The key input here is the weaving rates discussed in Section 3.10.1, based on UR III texts. It can be seen that the weaving rate for second-class cloth was 0.08 m/day. To calculate the number of days taken to weave one square metre is simply the inverse of this, that is, $1 \div 0.08 = 12.5$ days/m². The same texts show that the weaving rate of 0.08 m/s of required two workers. The total work required is simply the product of the two, giving 25 days/m². Applying this same rationale to the other cloth groups, the results are tabulated below.

| Class of cloth | Width of finished cloth m | Area of cloth woven m² /day | No. of days/m² | No. of weavers | Total man-days/m2 cloth |
|---|---|---|---|---|---|
| Second class cloth | 1 | **0.08** | **12.5** | **2** | **25** |
| Third class cloth | 1 | 0.25 | 4 | 3 | 12 |
| Fourth class cloth | 1 | 0.333 | 3 | 3 | 9 |
| Ration quality 4th class cloth | 1 | 0.5 | 2 | 2 | 4 |

**Table 4.32: Man days required to produce 1 m² of cloth, based on evidence from UR III texts**

## Total number of weavers required

The final stage is the computation of the total number of days required for weaving sufficient cloth to clothe 100,000 people, and the conversion of this workload of effort into weavers required. The workload is simply the product of the outputs from Stages 1 and 2, as shown tabulated below.

| Class of cloth | Egypt | | | Cyprus | | |
|---|---|---|---|---|---|---|
| | 1. Area of cloth m² | 2. Tot. man days /m² of cloth | Tot. man-days required | 1. Area of cloth m² | 2. Tot. man days /m² of cloth | Tot. man-days required |
| Second class cloth | 1,502 | 25 | 37550 | 3,453 | 25 | 86325 |
| Third class cloth | 12,450 | 12 | 149400 | 11,330 | 12 | 135960 |
| Fourth class cloth | 49,840 | 9 | 448560 | 52,125 | 9 | 469125 |
| Ration quality 4th class cloth | 154,781 | 4 | 619124 | 163,813 | 4 | 655252 |
| **Total workload** | **218,573** | | **1,254,634** | **230,721** | | **1,346,662** |
| No of days available for work | | | 347 | | | 347 |
| **Total man-days required** | | | **3,616** | | | **3,881** |

**Table 4.33: Total weavers' workload to produce the cloth to clothe 100,000 people/year**

If, after taking out days lost due to sickness, festivals etc., we can assume 347 days, then the number of weavers required for Egypt and Cyprus are 3,616 and 3,881 respectively.[712]

[712] As discussed above it has been assumed from textual, tomb paintings and ethnographic evidence that the bulk of cloth production would be carried out by women. It is assumed that the number of

## 4.10.5 Manpower requirements for wool and flax

In Section 4.6.4 the manpower required to cultivate flax to provide sufficient fibre to clothe 100,000 people was identified. Two cases were considered regarding the preparation of the ground for cultivation, ploughing and hoeing, and the manpower required to prepare the harvested green flax was evaluated in Section 4.7. The differences in manpower between wool husbandry and flax preparation are shown in the table below.

| Cypriot wool production | Workers required | Egyptian flax production | Workers required | | |
|---|---|---|---|---|---|
| Process | | Process | All hoeing | All ploughing | 70% hoeing 30% ploughin |
| Husbandry of flocks | 1,569 | Cultivation | 350 | 279 | 329 |
| Preparation of fibre | 440 | Preparation of fibre | 342 | 342 | 342 |
| **Total** | **2,009** | **Total** | **692** | **621** | **671** |
| | | Ratio Cyprus to Egypt | **2.9** | **3.2** | **3.0** |

**Table 4.34: Summary of manpower in preparation of wool and flax fibre for spinning**

This shows a clear productivity gain for flax fibre production over wool husbandry, irrespective of whether ploughs or hoes were used in cultivation, as shown by the respective productivity ratios ranging between 2.9 and 3.2. When spinning and weaving are added, these ratios are reversed in favour of woollen cloth production. The ratio of Egyptian linen workers to Cypriot woollen workers ranges between 1.444 and 1.437 depending on the assumptions used for flax production.[713]

| Cypriot wool production | Workers required | Egyptian flax production | Workers required | | |
|---|---|---|---|---|---|
| Process | | Process | Hoeing | Ploughin g | Assume for Egypt 70% hoeing 30% |
| Husbandry of flocks | 1,569 | Cultivation | 350 | 279 | 329 |
| Preparation of fibre | 440 | Preparation of fibre | 342 | 342 | 342 |
| Spinning | 4,540 | Spinning | 10,372 | 10,372 | 10,372 |
| Weaving | 3,620 | Weaving | 3,620 | 3,620 | 3,620 |
| **Total** | **10,169** | **Total** | **14,684** | **14,613** | **14,663** |
| | | Ratio Egypt to Cyprus | **1.444** | **1.437** | **1.442** |

**Table 4.35: Summary of total manpower requirements for woollen cloth compared with linen**

working days per year is 347 reflecting less sickness than agricultural workers who have been assumed to work 308 days per annum (see again Section 3.4, and Reports 3.29a, 4.9k, and 3.9g).

713 For the full analysis, Reports 4.10a-4.10e in CLOTHCALC.

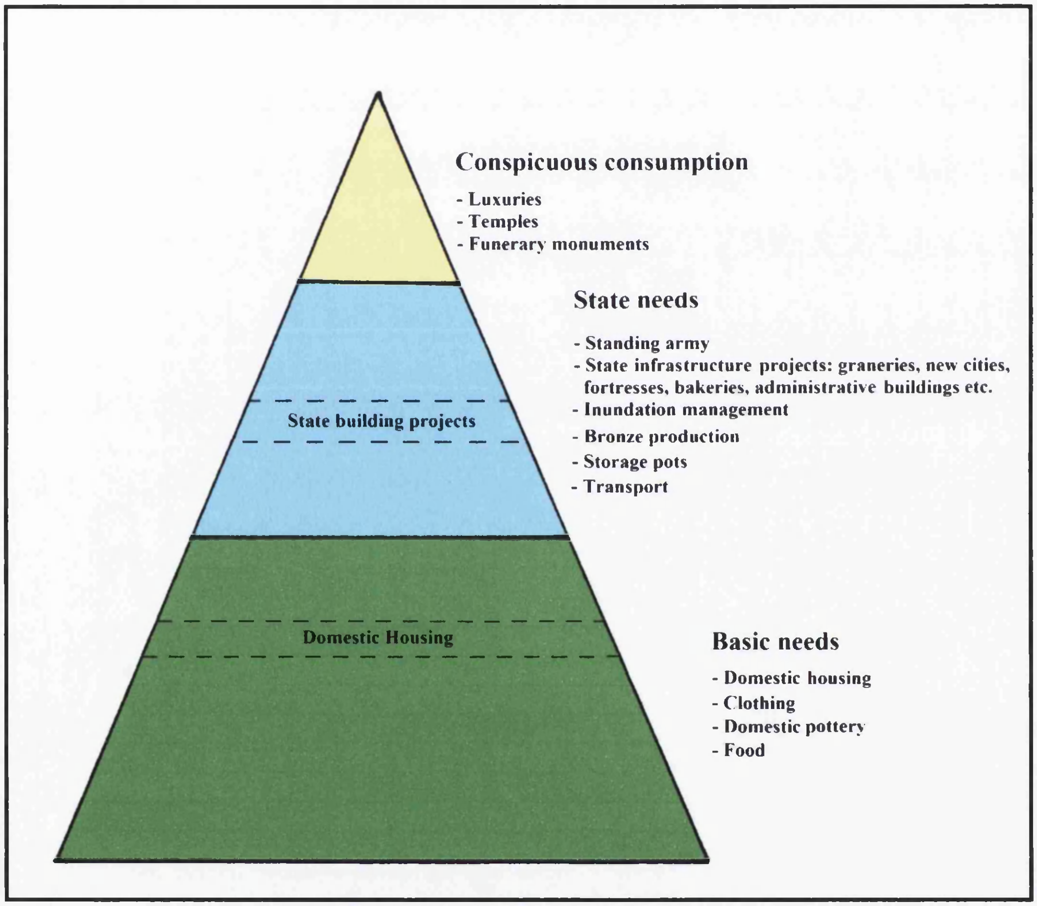
### 4.10.6 Summary

This chapter has demonstrated how ancient processes can be analysed from existing textual, archaeological, ethnographic, and experimental archaeological evidence. The model CLOTHCALC estimates that to provide sufficient cloth to clothe 100,000 people in Cyprus and Egypt would have required a workforce of 10,430 and 14,659 workers respectively. The difference in figures is attributed to Cyprus being assumed to make its cloth predominantly from wool, as noted in the table above.

# Chapter 5: Shelter

## 5.1 Introduction

The purpose of this chapter is to investigate the manpower needed to support the demand for domestic and state public building projects. As discussed in the introduction and summarised in the schematic below, shelter is, with food, and clothing, one of the three basic needs for humans. Domestic shelter is the third of the three basic needs studied in this thesis, food and cloth being previously covered in Chapters 3 and 4.




**Schematic 5.1 illustrating the relationship of domestic housing and state building projects to the hierarchy of needs of LBA cultures**

Religious and funerary-related buildings built of stone have been classified as examples of monumental building conspicuous consumption and will be discussed in Chapter 7. Investment in conspicuous consumption can only be allocated if basic needs and essential state infrastructure needs have already been met. Although many of the assumptions used in this calculation can only be at best informed guesses, the exercise has been valuable in showing that the resource requirements to fulfil the basic need for domestic buildings were comparatively small. State building projects, on the other hand, could be on a vast scale, as shown in the case studies below, and would have required significant reserves of the harvest surplus to feed the workers.

In the Aegean, mainland Greece, Cyprus, Anatolia, and the Levantine coastal strip, stone foundations with stone and or mud brick walls were the materials of choice for domestic, state, and religious structures.[714] The use of sun-baked mud bricks, particularly for building external walls, suited regions with low annual rainfall. In Egypt, where there was very little rainfall, sun-baked mud bricks were the norm for all domestic housing across all socio-economic groups. Stone was used in Egypt for all religious structures from the Third Dynasty onwards, however, and its use was connected to the associated symbolic aspect of timeless endurance, a mythological link with the beginning of time and the creation of the Cosmos.[715] It may seem surprising, given the versatility and ease of manufacturing mud bricks, that they were not used for all monumental buildings in Egypt, particularly as quarrying stone and transporting the blocks to the temple sites required vast resources, but to the Egyptians the determining factor for building material in these instances was its suitability for a place where the god or gods lived.[716]

In Mesopotamia, mud bricks were used almost exclusively for both domestic and monumental buildings, as good stone suitable for building was rare.[717] The Mesopotamians used sun-dried mud bricks, kiln-fired bricks, and for decorative work, glazed bricks. The scarcity of wood meant that kiln-fired bricks were used only for paving or for those areas particularly vulnerable to wind and water.[718] In order to estimate the demand for human and material resources to provide mud bricks for domestic shelter and state infrastructure building programmes, a number of

[714] Clark 2003: 34-43.
[715] Wilkinson 1999: 88-89.
[716] Oates 1990: 388-406. Mud bricks have many benefits over other building materials. They have better insulation qualities than stone or baked bricks, and are more versatile for construction purposes as they can be "... readily cut and shaped. Secondary changes of plan such as the insertion of a new doorway, niche or window are easily accomplished, and above all it does not require any great skill at least in the erection of simple structures" (Oates 1990: 389). Temples were called both 'the god's mansion' (hwt-nTr) or 'the god's house (pr-nTr). Stone possessed "... the characteristics of permanence, immutability, and incorruptibility that suggest the existence of another reality, another form of being which escapes the short-lived and corruptible of human life" (Ogdon 1985: 17-22). As the Egyptians had two concepts of time in parallel, cyclical and linear, Wilkinson 1999: 89 adds that "stone was viewed as a direct link with the beginning of time and thus with the creation of the cosmos itself".
[717] Oates 1990: 388-406, Oates and Oates 1989: 193-211, and Moorey 1999: 302-308.
[718] Moorey 1999:302.

case studies are included. To assist this analysis a spreadsheet was written, hereafter called SHELTER, and a copy is Volume 2.

## 5.1.1 Scope and specific objectives

Evidence has been drawn principally from tomb paintings, textual and archaeological sources, and modern Egyptian ethnographic studies. Modern studies have shown that mud bricks made in Ancient Egypt and Mesopotamia were made in a similar way to those made today, and therefore ethnographic evidence is particularly helpful for this study.[719] The only difference between Egyptian and Mesopotamian mud bricks is size and the proportions of chaff, straw, and sand, which will be discussed below. This study will concentrate on mud brick production in Mesopotamia and Egypt, as these areas had the largest populations and were the key economies of the LBA Eastern Mediterranean world. The evidence from well-preserved earthen construction materials from the sites of Vasiliki, Makrygialos and Mochlos in East Crete show that mud bricks appear to have been one of the most common building materials used in domestic architecture in Bronze Age Crete.[720] Mud bricks have also been found at Lachish and Tell Yinam (Israel) and Ezion-Geber: Elath on the north shore of the Red Sea.[721] From the evidence of the widespread use of mud bricks in the Aegean and the Eastern Mediterranean it has been assumed that Cyprus in the LBA followed the same practice.[722]

This chapter has two specific objectives:

1. To identify the scale of the domestic housing market and the resources required to support it
2. To illustrate the scale of state building projects, using six representative examples which used mud bricks.

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[719] Clarke 1908: 211-220, Fathy 1969, Kemp 2000, and Spencer 1979 outline the ethnographic, textual, and archaeological evidence for Egyptian mud brick production, as well evidence from tomb paintings. Aurenche 1981: 66ff and Moorey 1999:304-309 also examine the evidence for Mesopotamian mud brick production. All authors stress that the processes for mud brick making in use today in Egypt and Iraq have not changed significantly in nature since antiquity. I am grateful to R. Clark (Postgraduate student in the Department of Classics, Ancient History, and Egyptology) who supplied me references relating to the ethnographic evidence for mud brick production.

[720] Nodarou, Frederick, and Hein 2008. Also see Jerome 1993: 381-386 for analysis of Bronze Age mud bricks from Palaikastro.

[721] Goldberg 1979: 60-67 and Glueck 1940: 51-55.

[722] Even if the building material of choice for domestic buildings in Cyprus were locally-available uncut stones other areas of the Eastern Mediterranean show that manpower levels for the construction of domestic building are of the same order as mud brick buildings. The additional time collecting and lifting stones for building would have been on the same scale as the time taken to make mud bricks (Clark 2003: 34-43).

## 5.2 Process used to make mud bricks

The production of making mud bricks was a labour-intensive, repetitive and time-consuming task. Wet mud was mixed with chopped straw (*tibn*) and sometimes sand, using an agricultural hoe and the feet. Having filled the wooden mould with the mud/straw/sand mixture, the brick maker scraped off the surplus and removed the mould, leaving a mud brick that was strong enough even at this stage to retain its shape. Ethnographic evidence from Gourna in Egypt in the mid-twentieth century A.D. shows that a minimum of 45 kg of straw or chaff were mixed with one $m^3$ of mud and 0.33 $m^3$ of sand to make 660 bricks.[723] It was found that the bricks needed to be turned on their side after three days to minimise any cracking due to differential drying, and after six days the bricks were stacked ready for building.[724] The scene in the tomb of Rekhmire (Figure 5.1) clearly shows that the same process was used in the New Kingdom to make mud bricks (see flow diagram of the process below).[725] The text accompanying the scene reads: "Moulding bricks to build anew the storehouse of the temple of Karnak".[726] The Egyptian word for making a brick is *sẖt ḏbt*, meaning 'moulding' or 'striking' a brick'.[727] Moulds were made from pieces of wood joined together with mortise and tenon joints, and a mould excavated in the Middle Kingdom town of Kahun produced bricks that were 0.288 m in length, 0.146 m in width, and 0.084 m in depth (Figure 5.2).[728] Soil mixed with water to form a paste was also used as mortar which when dry formed a strong bond between the brick courses.[729]

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[723] Fathy 1973: 198. To make 660 bricks measuring 0.23 x 0.11 x 0.07m, a volume of 0.002304 $m^3$ that required 1 $m^3$ of soil, 0.33 $m^3$ of sand, and 20.4 kg of straw or chaff. To make 1,000 bricks would require 30.9 kg of straw. This equates to an area of 0.0215 ha growing barley.

[724] As Egyptian bricks in antiquity were structurally the same, this activity of standing the bricks on edge has been included as an activity in Report 5.1. Fathy 1973: 200 ethnographic evidence shows that three men took one day to turn and stack 6,000 bricks. This equates to 0.5 man-days per 1,000 bricks. For more details of the production process, see Clarke and Engelbach 1990: 208-209 and Kemp 2000: 83-84. For evidence of southern Canaan practice see Glueck 1940: 52-53.

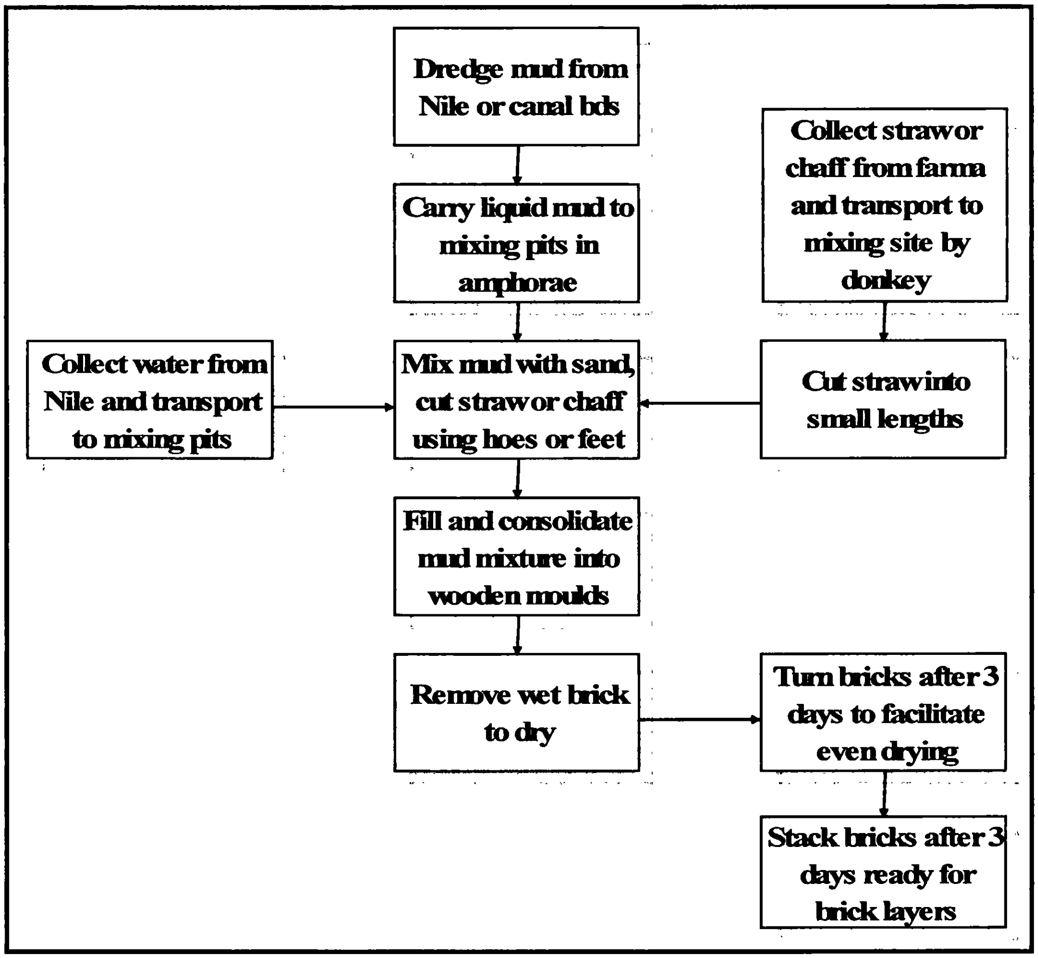
[725] Davies 1973: PLATES LVIII, LIX, LX and for coloured photographs, see Hodel-Hoenes 2000: Figures 117 and 118. It is difficult to see from the photograph, but examination of the painting shows that the artist has painted them a pink-grey colour, pink as they dry, and white when used by the builder (Kemp 2000: 83).

[726] Translated by Hodel-Hoenes 2000: 162.

[727] Badawy 1956: 63-64, Simpson 1963: 77-78, and Spencer 1979: 3-4.

[728] The online entry can be obtained from the website of The Manchester Museum. The University of Manchester *Brick-Mould.* Accessed 21st March 2007. Available from http://emu.man.ac.uk/mmcustom/Display.php?irn=320832&QueryPage=%2Fmmcustom%2FEgyptQuery.php. Manchester: The University of Manchester.

[729] Kemp 2000: 92.




**Schematic 5.2: Flow diagram for the mud brick production process**

## 5.2.1 Manpower required to make 1,000 bricks

Ethnographic evidence shows that four men could make 3,000 bricks per day, a rate of 0.75 man-days per 1,000 bricks.[730] However, in this case mechanical transport and modern tools were used to bring mud and sand to the site and to mix the brick constituents, nor were chaff or straw added to the mud mixture, with all the associated cutting and transport workloads which the process in Ancient Egypt would have involved. Report 5.1 shows that the ancient process described above would increase the manpower used significantly, from 0.75 to 8.1 man-days/1,000 bricks.

Brick sizes did change over time, as they were adapted for the type of structure being built, as shown in Report 5.1a. This would have had an impact on the time taken to make them, which is directly proportional to the volume of materials used in the

[730] Fathy 1973: 200.

brick.[731] For most periods they ranged between 0.30 and 0.45 m in length, 0.15-0.22 m in depth, and 0.075-0.15 m in height.[732] However, for any given building and time period, bricks of equal size were used, as these produced stronger walls, and the bricks were laid with alternate headers and stretcher brick courses. Similarly, to facilitate changes in wall direction at corners, the weakest part of any building, bricks were made with a length to width ratio of 2 to 1.[733] Mud brick sizes in Mesopotamia also varied considerably according to the time period and function of the building[734]. Mud bricks are particularly versatile, particularly making vaulted ceilings, as demonstrated in the New Kingdom granary in the Ramesseum (Figure 5.3).[735]

For the representative case studies in this thesis, it has been assumed that the effort to make bricks is directly proportional to their volume. Report 5.1a shows that a standard New Kingdom brick had a volume 1.47 times greater than a modern Egyptian mud brick, and so the time taken to make 1,000 bricks would therefore increase from 8.1 to 11.9 man-days per 1,000 bricks.

## 5.2.3 Building mud brick walls

Modern ethnographic evidence from Gourna in Egypt shows that one bricklayer can lay 2.5 $m^3$ of vertical brick wall in a day.[736] The modern Egyptian brick has a volume of 0.002304 $m^3$, so dividing the volume that can be laid per day by the brick volume

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[731] This assumes that the proportions of mud, sand, and straw or chaff remained the same. These proportions did vary, particularly regarding the sand and straw content. As the only variable would have been the time spent cutting the straw, which while not trivial (see Report 5.1), still remained a small part of the total process, it is assumed that volume is the best indicator of labour rate.

[732] The online entry can be obtained from the website of The Manchester Museum. The University of Manchester *Brick-Mould.* Accessed 21st March 2007. Available from http://emu.man.ac.uk/mmcustom/Display.php?irn=320832&QueryPage=%2Fmmcustom%2FEgyptQuery.php. Manchester: The University of Manchester.

[733] Generally with modern bricks this ratio is slightly lower, to allow for mortar between the bricks. It is interesting to note that the Kahun mould referred to above has a ratio of 1.97, presumably to allow room for the mud mortar. Kemp 2000: 87.

[734] Mesopotamian EBA mud bricks used in administrative buildings at Jemdet Nasr, Iraq varied between 0.2 × 0.085 × 0.08 m and 0.23 × 0.09 × 0.065 (Mackay and Langdon 1931: 290). The mud bricks from the outer walls of the Palace of Naram-Sin (c.2254-18 B.C.) at Tel Brak, located in modern-day Syria, measured 0.3 × 0.3 × 0.12 m (estimated from Oates 1990: ). Buildings at Lagash ca. 2410 B.C. used rectangular mud bricks of 0.33 × 0.24 × 0.6 m (Moorey 1999: 307). Wooley's report of Third Dynasty UR building excavations (2100-2000 B.C.) shows that later LBA Kassite (1600-1200 B.C.) and Neo-Babylonian ca.600 B.C contexts used mud bricks 0.32-0.33 m square, with thickness not specified (Wooley 1974: 57-60). For this analysis, brick sizes of 0.3 × 0.3 × 0.12 m will be taken as representative of the LBA.

[735] For a description of the method of making vaulted roofs based on Nubian ethnographic evidence, see Fathy 1973: 5-12, 211-213.

[736] Fathy 1973: 208.

results in a mud brick laying rate of 1085 bricks per day.[737] To lay bricks required up to four men to mix and carry the mud mortar and to supply the bricklayer with mud bricks, making a team of five men.[738] Archaeological records show that soft mud mortar was used throughout the Near East.[739] The size of the brick and the height of the structure being built influenced the number of bricks that could be laid in a day, and it is assumed that the number of bricks laid was again directly proportional to the volume of the brick. This means that a low wall that did not need scaffolding could be laid by a team of five men at a rate of 738 bricks per day.[740] To reflect the need for scaffolding and the additional effort of lifting mortar and bricks as the structure is built, manpower requirements are multiplied by factors on a sliding scale from 0-3 based on the height of the structure, the requirement for scaffolding, and the size of the brick.[741] For example, a bricklaying team laying much larger bricks on top of the wall of the enclosure wall (6.5 m high) around the Ramesseum on the West Bank at Thebes would only be able to lay 401 bricks, and the team size would increase to 15 men.[742]

[737] For mud brick sizes in modern and ancient Egypt, see Report 5.7d and 5.7e in SHELTER.
[738] Fathy 1973: 208.
[739] Kemp 2000: 92.
[740] The volume of a Middle Kingdom/New Kingdom was 0.00338688 $m^3$. The number of mud bricks laid per day therefore in the New Kingdom = 1085 × 0.002304 ÷ 0.00338688 = 738. The prorated results for brick-making and bricklaying for different mud brick sizes are given in Report 5.7f in SHELTER.
[741] Modern ethnographic evidence shows that mortar was mixed in the ratio of 1 to 2 of sand and sieved mud (Fathy 1973: 206). The high ratio of four people to supply the bricks and mortar to one wall builder is due to the speed at which the mortar dried out in the high ambient temperatures. To provide a good bond, the mud mortar must be wet, as the bricks soak up the water in the mortar. To overcome this problem, the man laying bricks requires a constant supply of mortar in small quantities, at the right consistency. Preventing the mortar drying out would have become even more of a challenge if time was needed to lift the mortar up scaffolding.
[742] For analysis and assumptions see Report 5.8f in shelter and Spencer 1979: 86.

## 5.3 Demand for mud bricks in New Kingdom Egypt

This section will be divided into three main parts. The first part will examine the scale of resources (manpower and materials) required to build three types of domestic housing at Amarna, the next part (Section 5.4) will examine state building projects such as granaries, enclosure walls, and fortresses, and the final part (Section 5.4.2) will be a specific case study of the resources required to build the 18th Dynasty capital city of Amarna. All assumptions, methodology, and calculations can be found in the spreadsheet SHELTER.

Amarna was the new Eighteenth Dynasty capital during the reign of Akhenaten (previously at Thebes), and was built over the short period of twenty years.[743] This town was chosen for the analysis of the resources required for domestic building because it provides a real case study of a town built in a well-defined period. The existence of the city of Amarna was short-lived, as the capital moved back to Thebes following Akhenaten's death, and so the city is a time capsule of Egyptian architecture, urban planning, and daily life. Despite the fact that much building material was recycled after abandonment, the foundations and lower brick courses of the domestic and public buildings, together with their associated artefacts, provide a remarkable record of domestic and civic building in late 18th Dynasty Egypt.[744]

### 5.3.1 Annual housing required to meet population growth

Population estimates vary considerably depending on the analytical approach taken. Most attempts to calculate population in the Pharaonic period start by estimating the total area of land that could be used for agrarian purposes and then multiply this by the number of people that could be sustained by this area using the agrarian

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[743] Akhenaten (Amenhotep IV) reigned from 1353 to ca. 1332 B.C and was the creator of the religious, artistic and political revolution that led to the creation of Amarna. Re and the sun disk Aten had increased in importance during the Eighteenth Dynasty, culminating with Akhenaten replacing the ancient triad of Atum, Shu and Tefnut with Aten, Akhenaten and Nefertiti (Akhenaten's wife) respectively. By regnal year five Amenhotep IV changed his name to Akhenaten, 'Servant of the Aten'. Atenism led to an inevitable conflict with the vested interests of the priesthood of the previous state god "Amun-Re".

[744] The Amarna project, under the directorship of Professor Kemp and working with the Egypt Exploration Society and the McDonald Institute for Archaeological Research of the University of Cambridge, is an example of all that is best about long term multi-disciplinary archaeological projects. The publications are extensive and a good introduction is the project's own website, accessed at http://www.amarnaproject.com.

technology available to them.[745] Estimates conflict and do not provide a clear understanding of population growth of Egypt over time. For example, Trigger estimates that Egypt in the Early Dynastic periods had a population of two million.[746] Butzer estimates for the Old Kingdom between one and two million and Hassan 1.1 million.[747] For the New Kingdom, Hassan's estimate is 2.1 million, but O'Connor gives a range of 2.8-4.5 million.[748] Kemp's population estimate for the Late Period is between four and five million.[749] For the Greco-Roman period, Clarysee and Thompson's population estimate is 1.5 million and Hassan's is 3.2 million.[750]

**Influence of pandemics on population levels**

This approach used by scholars of focusing on available agrarian land has been challenged by the ongoing work of Scheidel, who criticizes the very basis of such arguments. He believes that it is not the total amount of available agrarian land that controls population growth but age of first child, fertility, and disease, particularly pandemics.[751] He suggests that an area of 20,000 km was the maximum area that could be cultivated by the available number of males who survived into adulthood in the Ptolemaic and Roman Egypt.[752] This means that calculations frequently based on an estimate of land (18,450 km$^2$ and 27,300 km$^2$ for the periods 1800 and 150 B.C. respectively) available for cultivation overestimate the population available to maximise the land under arable production.[753] In other words, Egypt could not meet its full arable output potential because disease would have limited population growth.

Clarysee and Thompson used Scheidel's assumptions and linked them to their analysis of the Arsonoite nome census for 254-231 B.C., concluding that the average

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[745] Butzer 1976 has been the most influential scholar on the topic. A good example of a follower of Butzer's approach is O'Connor 1995: 319, who states the total arable land of Egypt in 1250 B.C. was between 6-8 million *arouras* (1.62-2.16 million hectares), which supported an estimated population of 2.8 million.

[746] Trigger 1983: 51.

[747] Butzer 1976: 81-85 and Hassan 1994: 83-89.

[748] O'Connor 1983: 190, O'Connor 1995: 319, and Hassan 1994: 83-89.

[749] Kemp 2002: 10.

[750] Clarysse and Thompson 2006: 100-101 and Hassan 1994: 83-89, particularly Figure 7.1.

[751] Scheidel 2001a: 162-166, 223, 248-249 and Scheidel 2007: 41-42, 66-73.

[752] Scheidel 2001a: 223.

[753] Butzer 1976: 82-84, Bowman 1996: 13, and Rathbone 1990: 107. For the period 1250 BC the total arable area of 18,400 km$^2$ is divided into: 13,000 km$^2$ in the delta, 9,000 km$^2$ in the valley, and 400 km$^2$ in the Fayum. For the period 150 BC total arable area of 27,300 km$^2$ the total arable area is divided into: 16,000 km$^2$ in the delta, 10,000 km$^2$ in the valley, and 1,300 km$^2$ in the Fayum.

population density was 60/ $km^2$ lower than many scholars' estimates.[754] This would give an extraordinarily low population for Egypt at the time, only 1.5 million.[755] Although Scheidel's work seems promising, this population estimate is significantly out of line with the current consensus of leading Egyptian scholars.

As Scheidel's demographic research into death and birth rates in antiquity is still in a stage of development, Hassan's rationale for Egypt's population growth has been used. Despite uncertainties in some of his assumptions, his population growth from the pre-dynastic to the modern period does follow a logical growth progression (Figure 5.4). His estimate for the population of the New Kingdom was 1.25 and 2.2 million.[756] Report 5.2 uses these population start and end points and calculates that the annual compound growth in the New Kingdom was 0.037695% per year.[757] With this compound growth rate, by the end of the New Kingdom, the population growth year on year would have been 829. With a family size of 6 in the New Kingdom, this annual growth would have required an additional 139 houses per 100,000 population to be built each year. The number of houses required to be built each year for the total population would be 3,058[758]

## 5.3.2 Resources required for increased housing demand

This section estimates the manpower required to build the required domestic housing to satisfy population growth. The previous section determined the demand for housing to satisfy population growth was 139 houses/100,000 population. Detailed stages of the analysis can be seen in Reports 5.3-5.5c. The manpower required was dependent on the size of the building, and this in turn reflected the owners' socio-economic standing. Tietze's typology study of Amarna housing designs showed that there were three main categories of living space for housing, workers,

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754 Rathbone 1990: 109 with an average maximum population density of 120 persons/$km^2$ and Bagnall and Frier 1994: 15, footnote 56 estimate ranging from 140-180 persons/$km^2$.
755 Clarysse and Thompson 2006: 100-101.
756 Hassan 1994: 83-89.
757 If the consensus changes, this will not invalidate the economic model, as it has been written in such a way that any assumption can be changed.
758 Kemp 1991: 157. My analysis in Report 3.21 in AGCALC, based on textual data from Ugarit, also indicates a family size of six. Szpakowska 2008: 37-38 and particularly footnotes 93-94 suggests a family size of 4 to 5, based on the fertility cycle of non-elite women. To this number should be added at least one adult relative, as the demographic analysis in Report 3.7b in AGCALC shows that 24.58% were over 40 and 13.77% were over the age of 50.

middle/professionals, and élite members[759]. A selection of these designs from Amarna is provided in Figure 5.5. Tietze's statistical analysis shows that domestic houses in Amarna can be allocated as follows: the working class 95.9%, professional middle class 3.4%, and the city élite 0.7% of the total[760]. The designs most representative of the three socio-economic groups are 1a-1c, 2d, and 3e (Figure 5.6).[761] The analysis in SHELTER calculates the number of bricks required and the manpower required building the specific house designs 1a-1c, 2d, and 3e used in this analysis, collates the demand for annual domestic housing by socio-economic group, and finally calculates the total manpower needed to produce them. Each stage is described in the following sections.

## 5.3.3 Mud bricks and manpower requirements

Tietze's typology is based on an urban environment and has to be adapted to reflect the fact that most of the population lived in non-urban environments.[762] Tietze's house designs 1a-1c, 2d, and 3e will be considered in this section. The bulk of these workers would have lived in house designs 1a-1c. Even in modern Egypt today the poorest agricultural workers live in mud brick houses similar to design 1a, and this probably also held true in antiquity. A few private farmers who owned their own land, given to them by the king, or who were affluent enough to lease land owned by temples would probably have aspired to larger houses of the 2d design.[763] The assumptions regarding the number of mud bricks needed and the calculations for manpower required to make the bricks and build house designs 1a-1c, 2d, and 3e are given in Report 5.3. A summary of the results is given below in the Table below.

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[759] Tietze 1985: 60-74.
[760] Tietze 1985: 83-84. Although large parts of Amarna have not been fully excavated, as some parts have been taken over by modern agriculture, aerial and more recently satellite imagery have helped to fill in the gaps. Tietze's sample size was sufficiently large for his results to be statistically significant.
[761] These designs were identified by calculating the floor area of these house designs and superimposing them on the histogram of the frequencies of houses collated by floor area, as excavated in central Amarna (Kemp 1991: 300, Figure 101).
[762] It has been assumed that workers with special skills, such as bronze casters, metal workers, faience makers, fine cloth makers, fine potters, and bakers, lived in urban areas.
[763] Kemp 1972: 675-676.

| House designs | 1a | 1b | 1c | 2d | 3e |
|---|---|---|---|---|---|
| No. of bricks required | 3,071 | 3,809 | 15,737 | 54,770 | 230,478 |
| Man-days to make bricks | 37 | 45 | 188 | 652 | 2,743 |
| Man-days to build house | 32 | 50 | 160 | 582 | 3,004 |
| Total man-days | 69 | 95 | 348 | 1234 | 5747 |
| **Total man-years** | **0.2** | **0.3** | **1.1** | **4.1** | **25.2** |

**Table 5.1: Number of mud bricks and man-days to make them and to build the house, collated by design type**

## Collating demand by socio-economic group

Collating annual house demand by socio-economic group is important, as house size depended on social position. The higher the social position, the larger the house, resulting in a need for more mud bricks and more manpower to make them and build the house. To collate demand by socio-economic group, SHELTER follows a number of steps:

## The population living in urban and non-urban environments

Report 5.4b in SHELTER shows that in the New Kingdom 9.5% of the population lived in urban environments and 90.5% lived in farms or small village communities (see table below).

| **Total population collated by socio-economic groups** | | **%** |
|---|---|---|
| Non-urban agrarian, cloth, bronze workers | 1,990,494 | 9.5 |
| Urban workers, middle professional classes, and the elite | 209,506 | 90.5 |
| **Population by socio-economic group** | **2,200,000** | **100** |

**Table 5.2: Total population collated by urban and non-urban sectors**

## Proportion of the population collated by socio-economic group

To collate the total population by socio-economic group, urban workers must be added to non-urban workers. Using Tietze's typology, 56.5% of the inhabitants of urban areas can been classified as workers, giving a total working class as collated in table below.

| **Total population collated by socio-economic groups** | | **%** |
|---|---|---|
| Non-urban agrarian, cloth, bronze workers+56.5% of Urban population | 2,108,865 | 95.9 |
| Middle professional classes | 74,375 | 3.4 |
| Urban elite | 16,760 | 0.7 |
| **Population by socio-economic group** | **2,200,000** | **100** |

**Table 5.3: Total population collated by socio-economic group, with urban workers added to non-urban workers**

## Total annual growth in population and housing

This section will analyse the Total annual growth in population and housing collated by socio-economic groups. The population growth per year of 829 people and a housing increase of 139 houses per 100,000 population identified in Section 5.3.1 has been collated by the same percentages and proportions given in Table 5.3 above, and is summarised in the table below.

| Total annual growth in population and housing collated by socio-economic groups | Population growth | Housing requirement |
|---|---|---|
| Non-urban population + 56.5% of Urban cities, towns etc | 795 | 133 |
| Professional middle classes | 28 | 5 |
| City elite | 6 | 1 |
| **Total** | **829** | **139** |

**Table 5.4: Annual population growth and housing requirements collated by socio-economic group**

One final adjustment is required to determine the number of bricks required to make the houses shown in the table above. Unfortunately despite the well preserved archaeological evidence of town, cities, and public buildings, built above the flood plain, the evidence for small farmsteads and rural villages is almost non existent. This is due to the fact that the Nile has moved across the valley floor at least once since the New Kingdom, destroying the archaeological evidence.[764] The lack of archaeological evidence from urban sites has been supplemented with evidence from tomb paintings and tomb models so that reasonable estimates can be made of the number of mud bricks required for each design of house type. The houses built by the majority of agricultural workers living in remote rural areas were probably more likely to reflect design 1a, rather than Tietze's 1c design that was more representative of the working classes in Amarna. To reflect this, greater weighting has been given to house designs 1a and 1b for non-urban areas in Reports 5.5a-5.5b of SHELTER and summarised in the table below.

| Total number of bricks required for annual housing growth | |
|---|---|
| Non-urban population + 56.5% of Urban cities, towns etc | 954,893 |
| Professional middle classes | 6,024,719 |
| City elite | 5,070,507 |
| **Total** | ######### |

**Table 5.5: Total bricks required to meet annual demand for domestic housing**

[764] Hillier, Bunbury and Graham 2007: 1-2, Figure 1.

## Manpower required to support annual domestic housing demand

Using a rate of 11.9 man-days to make 1,000 mud bricks, as discussed in Section 5.2.1, the manpower needed to make the required 1,459,221 mud bricks is provided in the table below. Similarly, using a bricklaying rate of 11.9 mud bricks per day, increased by the factors discussed in Section 5.2.3 the manpower required to build the houses is given in the table below.

| Manpower requirents | Making bricks | Building | Total |
|---|---|---|---|
| Agrarian population + 56.5% of Urban cities, towns etc | 11,363 | 9,680 | 21,043 |
| Professional middle classes | 71,694 | 63,983 | 135,677 |
| City elite | 60,339 | 66,087 | 126,426 |
| Total man-days | 143,396 | 139,750 | 283,146 |
| **Total man-years** | **466** | **454** | **920** |

**Table 5.6: Manpower required for making mud bricks and building the houses required to satisfy demand due to population growth**

In summary a total of 12,050,119 mud bricks were required and the total manpower required to make the mud bricks and build the houses was 920 man-years per 100,000 population. This shows that the manpower required for domestic housing was negligible compared with the total manpower needed for satisfying the other basic needs of food and clothing. This demand for manpower would not have had any meaningful impact on the economy, but this is not the case, however, for state projects, as will be shown in the in the next section.

# 5.4 Scale of state building projects

Unlike domestic building, state building projects required vast numbers of mud bricks to support the region's infrastructure. Towns and fortresses were built to support Egypt's economic and military interests, and new towns were created to provide labour and services for the building of major temples and royal tombs. New cities such as Amarna and Pi-Ramesses were built on virgin land, for political and religious reasons. The Egyptian climate has ensured that sufficient remains have survived in archaeological records to enable us to make reasonable estimates of the resources required to build them. To demonstrate the scale of the building industry to support state projects, three case studies have been taken into consideration.[765]

## 5.4.1 Case study 1: Representative state building projects

The first case study calculates the number of bricks and the manpower required to build five large mud brick structures. The scale of some of these mud brick buildings was enormous, as demonstrated in Figures 5.7 and 5.8. These have been chosen as they are representative of Egypt's need for city walls, fortresses, and granaries in the Middle and New Kingdoms. The same basic methodology that was used in Reports 5.3 for domestic houses has been used, but the sheer size and height of these structures meant that the building workload was far greater than for domestic building. The second modification in calculation reflects the fact that brick sizes varied depending on the function of the structure. For example, size and stability requirements necessitated that a fortress used much larger bricks (0.007992 $m^3$) than the standard Middle/New Kingdom brick (0.00338688 $m^3$), and so more time was needed to make them,. A summary of the examples chosen is given in the table below.

| State Project | No. of bricks | Man-yrs to make bricks | Man-yrs to build structure | Total man-years |
|---|---|---|---|---|
| Enclosure wall built for the Middle Kindom town of Lahun. | 6,160,537 | 239 | 194 | 433 |
| Enclosure wall of the town of Sesebi (between the 2nd & 3rd cateracts) | 10,343,292 | 400 | 325 | 725 |
| Granary built for the Nubian fortress of Mirgissa | 9,446,157 | 862 | 1,397 | 2,259 |
| The Middle Kingdom fortress at Buhen | 13,318,057 | 1,216 | 1,969 | 3,185 |
| Granary at the Ramesseum | 4,106,249 | 439 | 484 | 923 |

**Table 5.7: Summary of the numbers of bricks used and man-years required to make them and build examples of state projects**

[765] The full calculations for each of the case studies are provided in Reports 5.8-5.10, using the same production and building rates as used in Section 5.2.

It is not possible to determine an annual building rate in the New Kingdom, as this depended on many economic, political, and military factors. It is extremely likely that in the reign of any king one or more equivalent structures would have been completed.

## 5.4.2 Case study 2: Domestic housing for Amarna

The city of Amarna has been chosen for this case study, as it is unique in its scale and the speed of its construction. Two estimates have been given by Kemp and Janssen regarding the population of Amarna, 30,000 and 50,000 respectively. These population estimates can be collated by socio-economic class to establish the number of houses by socio-economic group, as summarised in the table below.[766]

| Percentage demographic population at Amarna | | | |
|---|---|---|---|
| | Tietze % | Kemp | Janssen |
| **Working classes** | 56.5 | 16950 | 28250 |
| **Professional middle classes** | 35.5 | 10650 | 17750 |
| **City elite** | 8 | 2400 | 4000 |
| | **100** | **30,000** | **50,000** |

**Table 5.8: Kemp and Janssen's estimates of the socioeconomic mix at Amarna**

The numbers of mud bricks required to build representative houses for the urban working class, professional middle class, and the city élite of have been calculated and are given in the tables below.

| Number of mud-bricks required | Kemp | Janssen |
|---|---|---|
| **Working classes** | 44,457,583 | 74,106,464 |
| **Professional middle classes** | 97,217,055 | 162,064,939 |
| **City elite** | 92,191,043 | 153,728,564 |
| | **233,865,681** | **389,899,967** |

**Table 5.9: Number of mud bricks to build all domestic housing in Amarna**

| No. of man-years | Kemp | Janssen |
|---|---|---|
| Working classes | 3,181 | 5,302 |
| Professional middle classes | 7,108 | 11,850 |
| City elite | 7,463 | 12,445 |
| Total | 17,752 | 29,597 |
| **Rounded total** | **18,000** | **30,000** |

**Table 5.10: Number of man-years required to make mud bricks and build domestic housing in Amarna**

The manpower needed to build the domestic housing in Amarna, up to 18,000 man-years, was comparable in scale to any of the more famous building projects of Egypt's Pharaonic history. A recent paper by Kemp states that the number of houses

[766] Socio-economic groupings are derived from Tietze's typology, as used in Appendix 1. For this analysis it is assumed that the size of a nuclear family is six members.

at Amarna, including an estimate of those now under modern cultivation, is 3,040, reducing the manpower requirement to 11,000 man-years.[767] To both estimates must be added the manpower resources needed for building the three Aten temples, palaces, temple bakeries, workshops, military barracks, and all the other commercial and administrative buildings associated with this large capital city. Some impression of the scale of these buildings can be seen in Figure 5.9. The religious centres were made of stone, and the royal palaces, although made of mud brick, were of a magnitude that made them far more complex than any of the élite houses (Figure 5.10). It is reasonable to surmise that the building of these additional buildings could easily have required double the manpower effort of the domestic buildings, perhaps in the region of 60,000 man-years, which makes a total of 90,000 man-years needed to build Amarna in 10-15 years.

## 5.4.3 Case study 3: State and private granaries

One of the highest state priorities in an economy that practiced redistribution was the storage of grain.[768] The tax taken each year from the harvest was stored in large temple granaries like those standing at the Ramesseum on the West Bank at Thebes. If we assume that ten per cent of the total harvest was taken in tax for redistribution to fund state and temple projects, a large number of granaries would have been required to store this. The analysis of food requirements discussed in Chapter 3 and included in Report 3.20e in AGCALC shows that the grain and pulse harvest required to feed 100,000 people weighed 33,222,367 kg and would have a dry volume of 48,587 $m^3$. If we assume that the population at the end of the New Kingdom was 2.2 million (see previous discussion) and that 10% of the harvest was stored for redistribution for non-agrarian activities, then the national granary storage requirement for taxation alone would be the equivalent of seven granaries the size of the Ramesseum (see Report 5.8f in SHELTER).[769] The total effort needed to build these would have been up to 6,461 man-years.

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[767] Kemp 2008: 34. The difference is due to the assumption in Report 5.7a that the population was 30,000 with a family size of six, giving a total house count of 5,000. Kemp suggests that there is evidence that slaves or hired home help also lived with lower socio-economic groups as well as with the elite, which would raise household inhabitants to ten.

[768] The practice of redistribution will be examined in more detail in the final chapter.

[769] This analysis uses Kemp's estimate, assuming that the Ramesseum held 16,522 $m^3$ of dry produce. Section 7.2.1 discusses redistribution strategies to minimise the impacts of failed harvests based on

If Amarna is representative, the harvest appears to have been collected and stored not in granaries of the size of the Ramesseum, which were used for tax and redistribution purposes, but in circular mud brick granaries (Figure 5.11). The average diameter was 2.5 m, holding a dry volume of grain or pulses of ca. 9.5 $m^3$.[770] This would require 112,530 Amarna-size granaries and a total of 20,838 man-years to make the bricks and, 16,907 man-years to build the granaries, giving a grand total of 37,744 man-years.[771]

the models given in worksheets FAMINE and GLUT in AGCALC. The result of this analysis shows that a storage strategy in state granaries of 10% of the average harvest combined with a reduction in rations of 20% in times of famine provides the optimum solution between minimising starvation and the cost of building and maintaining state granaries.

[770] Kemp 1991: 296, 309.

[771] The full analysis is given in Report 5.9 in SHELTER.

# 5.5 Chapter Summary

Archaeological records of Egypt and Mesopotamia clearly demonstrate the versatility and longevity of the use of mud bricks for architectural purposes. The simplicity of manufacture and the use of readily-available materials; mud, sand, and water, provided both cultures with a cost-effective solution to the basic need for shelter and the state's need for civic, military, and economic structures. Standardising brick sizes for any given building enabled complex architectural designs that were strong and stable, with minimal need for maintenance. The innovation of vaulted ceilings and possibly domes added further practical and aesthetic opportunities for domestic and state building programmes.

The cost-effectiveness of mud brick construction is demonstrated by the fact that only 920 man-years were required to keep up with the housing demands to satisfy Egypt's population growth. The versatility of mud bricks and their low cost as a building material meant that they satisfied all non-religious state building requirements. As a result of these two factors, huge building projects could be undertaken to satisfy state needs, sometimes with very sophisticated designs, such as the Ramesseum granary in the New Kingdom and Buhen in the Middle Kingdom. Had he used stone, Akhenaten could not have built the domestic buildings in Amarna in the time period he did.

The next chapter will consider manpower requirements to satisfy the need for bronze. This material has been chosen because bronze satisfied the state's need to compete militarily or economically within the 'global world' of the LBA Eastern Mediterranean.

# Chapter 6: Bronze

## 6.1 Introduction

The investment made in owning bronze would have been high on the priorities of the ruling élites of the period under study. Bronze, an alloy of copper and tin, was first produced in Afghanistan in the late fourth millennium B.C. and in Mesopotamia and Anatolia from ca. 3000 B.C.[772] Bronze could be acquired by importing tin and smelting it with indigenous copper, by importing both tin and copper, or by importing bronze itself. The funding for these imports and the cost of manufacturing bronze and bronze implements had to be met from the harvest surplus, which was needed to feed non-agrarian metal workers or the workers who produced added-value goods, such as glass, resin, or perfumed oils, which could be used in exchange for bronze, copper or tin.[773] Alternatively, surplus staples which were transportable, such as grain and olive oil, could themselves be used for exchange. This chapter focuses on the manpower required to produce bronze made from copper and tin. The manufacture of bronze was an important industry in the LBA, and by understanding the cost of producing bronze in terms of manpower, the scale of the metal industry can be determined. This will in turn contribute to the objective of this thesis, that is, to increase our understanding of the nature, operation and scale of the LBA economy.

Production of bronze was not a basic day-to-day necessity in the sense of housing, food and clothing, but was nevertheless a military and commercial necessity in terms of national security and for the tools required to make added-value goods for gift exchange and trade between regional élites. In addition, copper was not found universally across the Eastern Mediterranean, and this, combined with the collective need for tin to make bronze, resulted in a level of international trade not seen before the LBA.[774] Rich copper deposits were mined at different periods in the Bronze Age: in Anatolia, on Cyprus, in Northern Mesopotamia, at Timna in the Sinai Peninsula, and in the Eastern Desert of Egypt. Tin, however, was rare in the Eastern Mediterranean (Figure 6.1), and the earliest sources of tin ores in the Eastern

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[772] Pare 2000: 6 with full references of the early exploitation of bronze.
[773] For definition of 'added-value', see again Section 1.1 Chapter 1.
[774] Trade implications will be covered in more detail in Chapter 7.

Mediterranean were mined mainly in the central Taurus Mountains in Anatolia.[775] By the end of the EBA, these mines had become exhausted and the consensus of scholars is that the majority of the supply was imported from central Asia (Figure 6.2).[776] Textual and archaeological evidence overwhelmingly demonstrates that by the LBA most, if not all, tin imported into the Eastern Mediterranean was probably transported overland from Uzbekistan, Tajikistan or Afghanistan.[777]

Bronze alloyed with tin is easier to cast than copper, thus lowering production costs as well as providing weapons and tools with greater mechanical strength. This made tin a commodity of strategic importance for all regions, and had a profound effect in stimulating the LBA Eastern Mediterranean economy. As tin for bronze production had to be sourced outside the Eastern Mediterranean, an international metals market developed, which obliged the Eastern Mediterranean regions to produce and exchange added-value goods or other valuable raw materials for tin.[778] Even Egypt, with its wide range of natural resources available to them in the Old and Middle Kingdoms that had enabled them to remain relatively economically and politically isolated, was forced to trade for tin outside its borders in the New Kingdom.[779] Ugarit may well have been the distribution centre for the tin, using the harbour at Mahadu, close to Ras Shamra.[780]

The term bronze can itself be confusing, as some scholars use it in a wider sense than others. Some use the term to refer to an alloy of copper and tin alone, while others include ternary alloys such as copper-tin-arsenic (arsenical bronze) and copper-tin-

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[775] Particularly the Kestal mine and its associated mining village of Göltepe 40 km north of the Bolkardağ mining district (Yener and Özbal. 1987: 220-226.Yener, K. A. and P. B. Vandiver. 1993a: 207-238, and Yener 2000: 71-109). Tin has also been found in ancient slags from Bakir Çay, 260 km northwest of Ankara in the Amasya province of Turkey (de Jesus 1980: 55-57).
[776] Discussed in Appendix 3, Section 3.3.
[777] Cierny and Weisgerber 2003: 21-33.Cleuziou and Berthoud 1982: 14-19, Dayton 2003: 3-13, Gillis *et al* 2003: 103-110, Kassianidou 2003a: 109-119, Maddin, Wheeler and Muhly 1977: 25-47, Muhly 1985: 275-291, Muhly *et al* 1991: 209-220, Muhly 1993: 239-253, Weisgerber and Cierny 2002: 179-186, and Yener, Vandiver and Willies 1993b: 255-264.
For a modern mineralogy review of tin deposits in Central Asia that may provide locations of Bronze Age tin mining sites see Ludington and Peters 2007: 106-114.
[778] This topic will be discussed in more depth in Chapter 6.
[779] Egypt does have tin deposits of cassiterite in the Eastern Desert which is mined today (Sabet *et al* 1976: 169-180. There are no textual references to tin mining within Pharaonic Egypt though a few tin objects have been found in funerary contexts (Ogden 2000: 171).
[780] Astour 1970: 113-127.

lead (lead bronze).[781] In this thesis the term bronze will be restricted solely to the manufactured alloy of copper and tin unless otherwise stated. The mix of copper and tin varies considerably in ancient bronzes, but by the LBA the most common ratio for tools and weapons was 90-95% by weight of copper alloyed with approximately 5-10% of tin by weight.[782] The source of the tin was probably tin stone ($SnO_2$), discovered as a by-product of panning alluvial gold.

## Arsenical Bronze

By the LBA, all cultures were increasingly using copper and tin bronze as the copper alloy of choice. It should be remembered however that before this period copper or copper naturally alloyed with arsenic had been used and continued to be used to make metal artefacts. In Egypt arsenical copper took precedence over bronze until well into the New Kingdom.[783] Arsenical copper had clear metallurgical advantages over copper, being harder and maintaining a cutting edge on tools and weapons for a longer period.[784] If copper to arsenic ratios are similar to those of copper and tin in bronze, similar metallurgical properties are achieved in terms of hardness and longevity of the cutting edge.[785] In Cyprus the amount of arsenic in sulphide ores is generally low, around 0.02%, which is too low a level to influence the mechanical properties of artefacts made from the ore.[786] Arsenical copper had a major disadvantage, however, over bronze in terms of manufacturing. Arsenic ores were less stable than tin ores when heated, and they released arsenic gases, creating two major problems. The first was controlling the mix of arsenic to copper. If arsenical copper was to be used for tools or weapons comparable to the mechanical properties of copper/tin bronzes, the copper required arsenic levels above 5%. The volatility of

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[781] Pare 2000: 13.

[782] All copper ores have some level of impurities. It is generally assumed that any ore with more than 1% tin or arsenic is taken as the dividing line between a natural alloy and a deliberately-produced alloy (Ogden 2000: 153). The majority of artefacts by the end of the LBA are closer to 90% copper/10% tin ratio than the 95% copper/5% tin ratio (Ogden 2000: 154).

[783] Ogden 2000: 153. From the Ramesside period onwards the majority of artefacts made in Egypt were made from copper-tin bronzes and after the New Kingdom finds of arsenical bronze artefacts found in the archaeological record are rare. Lucas and Harris 1962: 220 notes that there was more arsenical bronze in Tutankhamun's tomb than bronze.

[784] Arsenical copper remained harder than copper even after prolonged forging at high temperatures. (see Budd and Ottaway 1995: 95, with full references in footnote 1).

[785] Pernicka 1998: 135-136.

[786] Giardino, Gigante and Ridolfi 2003: 308. The exceptions are at Laxia tou Mavrou near Dheironaa and at Pevros in the Limassol forest. Ores from these two areas show up to 7.6% arsenic content.

arsenic when heated made it difficult for ancient smelters to achieve any consistency in the levels of arsenic using the smelting technology available to them at the time.[787] The second problem, of course, was that arsenic gas was extremely toxic for those smelters who were close to the furnace.[788]

## 6.1.1 Objectives and scope

The first objective of this chapter is to calculate the manpower resources required to mine, smelt, refine, copper and tin and then alloy them together to make bronze.[789] The second objective is to determine the manpower required to make and transport the ten tons of copper and one ton of tin ingots found on the Ulu Burun wreck (Figures 6.3-6.4).[790] The findings from these quantitative studies will be used in Chapter 7 to investigate the relationship between the 'cost' of production and the attested textual evidence of the value of copper, tin and bronze traded in the LBA.[791]

1. The textual and archaeological evidence will be examined to identify or quantify:
2. The sources of copper and tin in the LBA.
3. The provenance of the copper and tin ores used to make bronze ingots and artefacts found in LBA archaeological records.

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787 Pernicka 1998: 136-147 and Ogden 2000: 153.

788 Charles 1978: 30. For an in-depth analysis of the toxicological implications of ancient copper mining and smelting in Wadi Faynan, south-western Jordan, based on Roman skeletal evidence, see Grattana *et al* 2002: 207-307.

789 Concise definitions of metallurgical terms used in this chapter are given in the glossary at the end of the chapter.

790 Ten tons of copper equates to approximately 325 talents, given that a talent of metal is estimated to have been between 28-29 kg (Pulak 1997: 251 and Pulak 2000b: 263). The Ulu Burun wreck sank ca. 1318± 21 B.C. off the Lycian coast in Turkey (Figure 6.5 for the sites of all known LBA wrecks). Comparisons will also be made with the Gelidonya wreck that also sank off the southern coast of Turkey. Both wrecks have been fully excavated under the directorship of Pulak and Bass. The underwater excavation of Pulak and Bass has been extensively documented by themselves and by other members of their underwater team. Their contributions set a new benchmark for excellence in underwater excavation. See Bass 1961: 267-276; Bass 1967a: 44-47; Bass 1967b: 84-121; Bass 1967c: 52-83; Bass 1972: 12-36; Bass 1986: 269-296; Bass 1991: 69-82 and Bass 1997: 153-170, Bass *et al* 1989: 1-29, Pulak 1988: 1-37; Pulak 1997 : 233-262; Pulak 1998: 88-224; Pulak 1999: 209-238; Pulak 2000a: 28-34; Pulak 2000b: 247-266 and Pulak 2001: 13-60.
A wide range of goods were carried on this ship beside copper and tin (Figure 6.6, illustrating the Ulu Burun and its cargo). For a comprehensive summary of the Ulu Burun cargo, see Pulak 2001: 13-60 and an illustrated catalogue in Yalçin, Pulak and Slotta 2005: 560-677. For comparison with another boat from the LBA, see Figure 6.7 for a reconstruction of the Point Iria.

791 The validity of using the term 'cost' in discussions on the Ancient Economy will be covered in detail in Chapter 7, Section 7.6. Throughout this thesis cost is measured in terms of satisfying the daily food requirements supplied from the harvest surplus left over after the agrarian and textile workers and their families had been fed.

4. The scale of the bronze industry in the LBA.
5. The process and manpower needed to mine and prepare ores and charcoal for smelting, smelting and refining copper and tin.
6. The process and manpower required for alloying copper and tin to make bronze castings.

## 6.1.2 Methodology

The methodology used for this chapter follows closely the approach used in the analysis of food and cloth production in Chapters 2 and 3. The bronze production process used in the LBA, from mining the ores through to the casting of bronze, is identified and broken down into discrete activities that follow each other in a logical sequence.[792] The time taken to complete each activity is estimated, which enables the number of workers required to be calculated.

### Evidence used

Any study related to mining in antiquity has a problem not normally faced by standard archaeological excavations. Most excavations reflect an accumulation of material over time through human activity, but in ancient mines the reverse occurs, with early activity removed by later mining activity.[793] Nowhere is this more evident than the Cypriot mines around the Troodos Mountains, where much evidence has been destroyed by Roman and medieval mining operations and also by modern open-cast mining and the use of ancient slag heaps for road construction.[794] It is fortunate that the ancient mines at Timna (Figure 6.8) have largely escaped destruction from continued mining, and the partially intact LBA Cypriot mines at Politico Phorades and Apliki also give some indication of techniques used to mine and smelt sulphide ores.[795]

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[792] See earlier discussion on *chaînes opératoires* in the Introduction.
[793] Weisgerber 2006: 2.
[794] See Koucky and Steinberg 1982: 151, Figure 2 and Weisgerber 2006: 4, Figure 2, which show the removal of a large ancient slag heap north of Polis, used for road construction.
[795] These mines are located in the secondary weathered sulphide ores found in the pillow lavas surrounding the Troodos Mountains, and their geology will be discussed in Appendix 3 Section 3.1. For the surviving archaeological evidence for these mines, see: Knapp 1999a: 98-109 with full references for LBA mining evidence in Cyprus; Kassianidou 1999: 91-97 for smelting evidence at Politico Phorades; du Plat Taylor 1952: 133-167, endnote 38 for settlement and mining evidence for the Apliki; and Koucky and Steinberg 1982a: 178 for the Apliki furnace.

There are many gaps in our understanding of the complete end-to-end copper production process, and these will be filled by using indirect evidence from experimental archaeology, scenes of metal processing in Egyptian tomb paintings, ancient and classical textual evidence and recent ethnographic evidence.[796] Modern scientific studies have also increased our knowledge of ancient metal-working processes and the provenance of metals.[797]

Archaeological records show that Cyprus and Timna in the Arabah Sinai copper fields were being mined in the LBA, and these two sites have been chosen for the analysis of copper production in the quantitative study because they represent low and high-cost operations in terms of manpower. The relatively easy access to the copper sulphide ores on the edges of the Troodos Mountains, using adit or open-cast methods, made this a low-cost operation (Figure 6.9).[798] In contrast to the more difficult mining operations carried out in the LBA at Timna in the Arabah of the Negev Desert in Sinai. Here complex interconnected tunnels were necessary to follow the veins of mixed oxide ores in nodular form, and the removal of waste rock (hereafter called gangue) from the tunnels and access shafts made this a very labour-intensive process (Figure 6.10).

Section 6.2 describes the copper, tin, and bronze production processes in the LBA. This section provides the assumptions used for the quantitative analysis that models and calculates the manpower for this 'end-to-end' process, from mining the copper and tin ores through to the casting of bronze. The sequence of actions taken to produce bronze is shown below in the process schematic 6.1 below. The time taken

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[796] The experimental archaeology sources used in the quantitative study are Crew 1990: 57, Earl and Yener 1993: 163-175, Lewis 1990a: 55-56, Marechal 1985: 29-41, Merkel 1983a: 173-178, Merkel 1983b: 32-72, Merkel 1985: 164-169, Merkel 1990: 78-122, Pollard, Thomas and Williams 1990: 72-74, Py and Ancel 2006: 71-82, Timberlake 1994: 121-130, Tylecote and Boydell 1978: 27-51, and Tylecote and Merkel 1985: 3-20. For ethnographic evidence, see Merkel 1983b: 141-158.

[797] The number of papers published on provenance investigations, particularly the contentious issue of lead isotope analysis, is considerable and too long to list here. The leading protagonists are N. Gale and Z.A. Stos-Gale, and the antagonists are P. Budd, A.M. Pollard, B. Scaife and R.G. Thomas. A review of this topic and its importance to the provenance of metal ores and artefacts is given in Appendix 1.

[798] LBA Cypriot adit and open-cast mining, Ramesside Egyptian shaft and tunnel mining at Timna, and LBA trench mining for tin in Uzbekistan will be discussed in detail in Section 6.21 below.

to complete each activity is estimated which enables the number of workers required to be calculated.[799]

The calculation method uses an Excel spreadsheet to calculate the manpower to produce one kg each of copper, tin and bronze (man-years/kg). The spreadsheet is interactive, so all the input variables can be changed to reflect any variance in the assumptions. This spreadsheet model will be referred to hereafter as BRONZECALC. Using this model the total man-years required to make the copper, tin ingots and bronze found on the Ulu Burun wreck is calculated. The total man-years of effort will indicate the cost of the ship's metal cargo and what proportion of the harvest surplus it represents. BRONZECALC is modular in design and analyses:

1. The quantity of ore required to be mined to produce one kg of copper or tin
2. Mining the ore
3. Preparation of ores for smelting
4. Smelting of copper and tin
5. Refining, alloying and casting of copper and tin to make bronze
6. Transport of men and ingots
7. Charcoal requirements
8. Supplies of food and fodder required to support the metal workers

Appendix 1 provides glossaries of metallurgical and chemical terms associated with the production of bronze. A copy of BRONZECALC is provided in Appendix 6, and a summary of the assumptions used for each module is included in Report 6.1 in BRONZECALC.[800]

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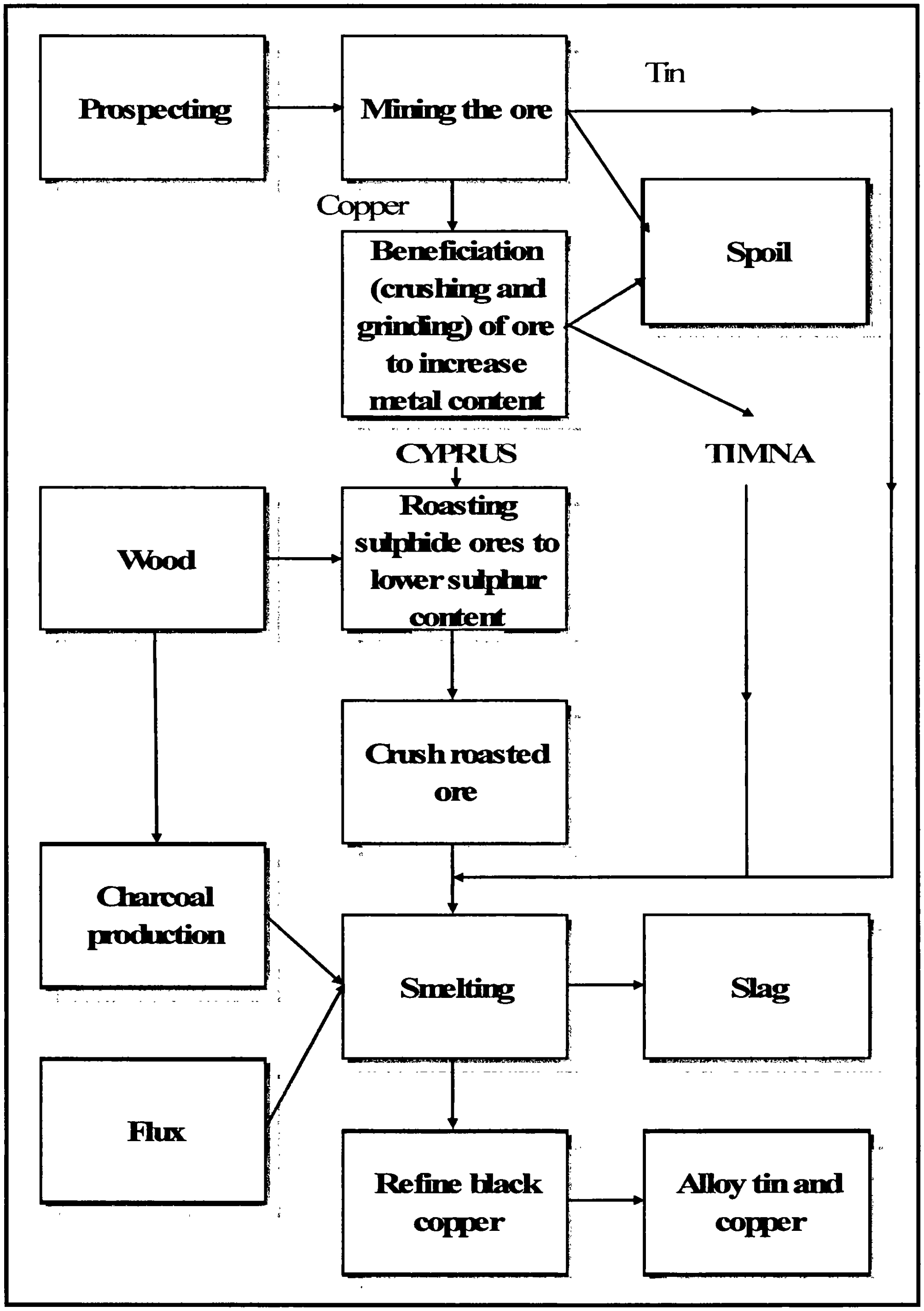
[799] The same technique is still used today in modern process engineering. For applications to ancient technologies, see Cresswell 1990: 46 and Sillar and Tite 2000: 3-4.

[800] Module 9 is an additional module that demonstrates the scale of the LBA bronze industry by calculating the manpower requirements of three case studies: the production of the weapons required to support the army of Ramesses II, the bronze requirements for tools used in agriculture, and the bronze tools used by craftsmen. The results of this analysis will be discussed in Section 6.2.2 relating to the scale of the LBA economy of Cyprus and Egypt.

# 6.2 Manpower required to produce bronze

This section will examine the manpower required to make bronze in the LBA. The analysis follows the production process, from the extraction of ores through to the alloying of copper and tin to make bronze. The sequence of steps mirrored in BRONZECALC will follow the logical flow of materials and operations shown in the schematic below.




**Schematic 6.1: Process from mining copper and tin through to the production of bronze**

Module 1 in BRONZECALC will analyse the ore requirement, and Modules 2-6 will analyse mining, the preparation of ores for smelting, smelting, refining, and transporting black copper and alloying tin and copper. One major operation that absorbed significant manpower was the production of charcoal and this will be covered separately in Module 7. Each part of the process the manpower calculated in BRONZECALC has a minimum and maximum case reflecting the uncertainty of some of the variables chosen for the analysis.[801] The sequence of calculations follows closely the flow diagram of the metals process given in the schematic above. If a more detailed understanding of the algorithms is required they can be reviewed in the printed output of BRONZECALC given in Appendix 6. Specific technical terms are used in the text and are fully defined in the metallurgical glossary in Appendix 2A. To illustrate the operation of smelting, refining and casting processes some associated chemistry will be discussed. In all cases standard conventional nomenclature will be used. Appendix 2B provides a glossary of the chemical abbreviations used in the text and BRONZECALC.

## 6.2.1 Mining the copper and tin ores used to make bronze

This section will be divided into three parts. The first part will examine the mining landscape of Cyprus and Timna to provide context for the LBA mining processes. The second part will analyse the excavation methods associated with ancient mines so that the volume of ore and gangue to produce one kg of either copper or tin can be established. This provides the input assumptions to calculate the manpower required to mine the ores discussed in Part 3. Two types of copper ores have been analysed; the sulphide ores mined in the LBA Cypriot mines at Apliki, and the copper-rich nodules mined at the Ancient Egyptian mines around Timna in the Arabah. Tin mining is represented by the tin trench mines in Uzbekistan in central Asia.

The manpower required to extract the ore will be estimated for each location. It will specifically estimate the man-days needed to excavate the quantity of ore required to

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[801] The major variables being the weights of the copper and tin ingots in the Ulu Burun wreck. Pulak and his team found that the ingots varied due to corrosion (Pulak 1997: 235-239, Pulak 2000c: 143 particularly Figure 7, with a histogram of weight distribution). The total weight of the oxhide and bun ingots after drying was 9,525 kg, and assuming a 10% allowance for corrosion, that would give a maximum value of 10,478 kg (Lin 2003: 206, Table 7.1). The weight distribution for the tin ingots is less clear, due to transformation while in the sea from metallic to grey tin (Pulak 2000c: 152). The total weight of the tin ingots is assumed therefore to be ca. 10,478 kg (see Pulak 2000c: 151-152).

make one kg of copper and one kg of tin, and this will also include any spoil that would have inevitably been excavated with the ore. For reasons of clarity, the spoil created by the valueless rock component of metal ores when mining underground is hereafter called gangue, and the spoil that overlaid the sulphide ores from the open-cast pits is hereafter called gossan.[802] BRONZECALC in Reports 6.1.1-6.1.4 calculates the volume and weight of ore and gangue which had to be excavated to make one kg of ore and tin. Reports 6.2.1-6.2.6 in BRONZECALC calculates the manpower needed to excavate these quantities of ore.

## Part 1: The mining landscape in the LBA

This section will discuss the geology, mining landscape, and provenance of the ores used in the LBA Eastern Mediterranean. Understanding the geology of a mining area helps us to interpret the types of ores available for exploitation within the constraints of the level of mining and smelting technology available in the LBA. The landscape of the mining district determines the likely locations of the mine sites and the conditions under which the metal workers had to operate. The provenance of copper ores underpins the assumptions made for this study that Cyprus and Timna were major copper producers in the LBA. The provenance of tin, however, still remains an enigma. Recent archaeological studies show that tin was mined in antiquity in Uzbekistan, Tajikistan, East Kazakhstan, and possibly Afghanistan (hereafter grouped together as central Asia), but no conclusive evidence has been produced that directly identifies these areas as the source of tin used in the LBA Eastern Mediterranean.[803] The large quantity of tin ingots found on the Ulu Burun and Gelidonya wrecks, and off the coast of Israel at Kfar Samur, demonstrates that large quantities of tin were circulating around the Eastern Mediterranean.[804] Although

[802] Gossan (iron cap) is a weathered iron-rich product overlying the exposed sulphide deposit mix, formed by the oxidation of the sulphides of copper by the percolation of rainwater through the veins of minerals.
[803] Discussed in more Section 6.2.1 and Appendix 1.
[804] In the Kfar-Samir region south of Haifa, at a distance of 100-150 m offshore, plano-convex tin ingots and small (2–4 kg) perforated lead ingots bearing Cypro-Minoan signs, and a group of five one-holed stone anchors, one engraved with a scarab design, were found. The southern cargo was located ca. 600 m to the south, and included two whole ox-hide ingots, 10 small (3–5 kg) tin ingots and seven large (20– 30 kg) tin ingots, some of them perforated and/or bearing Cypro-Minoan inscriptions (Galili 1984, Galili, Shmueli and Artzy 1986: 25-37, and Galili and Rosen 2007. For Cypro-Minoan markings on copper ingots found on the Ulu Burun wreck, see Figure 6.3d.

evidence is unsatisfactory, by default central Asia appears to be the most likely candidate as the source of this tin.

Understanding the landscape where ancient mines were situated helps to minimise the problem that the majority have been destroyed by later mining operations. Knapp has developed a four-tiered settlement model for LBA Cyprus from his study of the topography of the island and how this influenced ancient processes.[805] The landscape dictates where mines are situated, with the farming hinterland necessary to support them, available water and energy sources, practicable transport routes into and out of the mines, the optimum location of administrative centres, artefact production centres and finally the location of ports for import and export of copper and tin. This settlement model has been particularly helpful in this study by indicating the likely routes of materials from the LBA mines on the northern slopes of the Troodos Mountains, such as Apliki and Politico Phorades, to the probable LBA refining centres in the ports of Enkomi, Hala Sultan Tekke, and Kition.[806]

**Geology associated with Cyprus and Timna**

The geology associated with a mining district dictates the types of metal ores that could have been exploited with the mining technology available in the LBA. For example, the massive sulphide deposits deep below the pillow lavas in the Troodos Mountains in Cyprus, mined extensively today using modern open-cast mining technology, would have been beyond the capabilities of the LBA miners (see again Figure 6.9).[807]

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[805] Knapp 1996: 54-80, Knapp 1997a: , Knapp 1997b: 156, Knapp 1999a: 98-109, Given *et al* 1999: 19-39, Knapp and Ashmore 1999: 1-30, Layton and Ucko 1999: 2-3 and Kassianidou 2003b: 214-219.

[806] One notable success of this landscape approach was the discovery of the LBA industrial metal-working complex at Politico Phorades, which was probably linked to the nearby Kokkinorotsos mines. Applying Knapp's landscape methodology, the Sydney Cyprus Survey Project were able to narrow down the possible number of ancient mining sites, therefore optimising the number of field studies required (Knapp, Kassianidou and Donnelly 1999: 124-146, Knapp, Kassianidou and Donnelly 2001: 204-210, Kassianidou 1999: 91-97, and Kassianidou 2004: 96).

[807] Note that the closest the mass of sulphide ore reaches to the surface in the Troodos Mountains is 45 m. Even in the Roman period, mine-draining systems at the Rio Tinto copper mines, using a succession of eight pairs of water wheel pumps, could only raise flood water a total of 29.6 m. The system was labour-intensive, requiring 16 men to operate the wheels (Landels 2000: 68-70, Figures 16-17).

Copper was exploited in the Neolithic period ca. 7000-6000 B.C., as is confirmed in the excavations at Catal Hűyűk in Anatolia.[808] Copper can be obtained in five main forms: naturally-occurring nodules and veins of copper, copper silicate ores, copper hydroxyl oxides and copper hydroxycarbonate ores, and copper sulphide ores. Natural copper can be excluded as a source for the LBA, as by the end of the Chalcolithic period most of the natural copper available on or near the surface had been used up.[809] The copper silicate ores found in the Lower Cambrian rock formations at Timna can also be excluded for the purposes of this study, as these were beyond the mining capabilities of New Kingdom Egyptians. At Timna the copper nodules mined and smelted in the LBA were predominantly complex mixtures of copper hydroxyl oxide and copper hydroxycarbonate ores. Supplies of oxide and hydroxycarbonate ores were found in the secondary enrichment zones in Cyprus (discussed below), but these had been largely exhausted by earlier mining activity. In the period of the Ulu Burun and Gelidonya wrecks, almost exclusively copper sulphide ores were used in large- scale copper production.[810]

The geology and chemistry of the ores from the two sites chosen for the quantitative analysis, namely the Apliki mines on the pillow lavas of the Troodos Mountains and the Egyptian copper mines at Timna in the Arabah, will now be examined in more detail. The geology indicates the type of ore that could be mined with the technology available to LBA miners, and where it was located.

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[808] Tylecote 1962: 5.

[809] Natural copper had the benefit of not requiring smelting, but artefacts made from it by cold working with hammers required annealing to avoid cracking (Coghlan 1975: 20). Annealing was known to the Egyptians, as attested by a text accompanying scenes of copper-working on the tomb wall of Wepemnofet. It states 'There is no cracking if it is heated excellently' (Weinstein 1974: 23-25). For sources and use of natural occurring copper. see Rapp 1999b: 701-702 and Moorey 1999: 242.

The main oxide ores are cuprite, melaconite and tenorite, the hydroxycarbonate ores are azurite, and silicate ore chrysocolla. The main sulphidic ores are bornite, chalcocite, covellite, and, the most common ore of all, chalcopyrite. Some of these ores contained other trace elements, particularly arsenic, which played an important role in ancient metallurgy. The copper arsenide ores most likely to have been used in antiquity were probably domeykite, algodonite, and koutekite. When these ores were smelted, they formed natural alloys with the trace elements that significantly improved the mechanical properties of the over-pure copper. This will be discussed below.

[810] See discussion on lead isotope analysis below for the evidence that the ingots on the Ulu Burun and Gelidonya wrecks were made from sulphide ores.

## Copper ores from Cyprus

The main copper sulphidic ore fields are located underneath the pillow lava beds that surround the edge of the Troodos Mountains (Figure 6.12). Archaeological and lead isotope evidence (discussed below) suggests that LBA copper mining was centred along the northern edge of the Troodos Mountain pillow lavas.[811] The evidence suggests that copper deposits along the southern edge were exploited mainly in the Chalcolithic period and not the LBA.[812] The primary copper ores found in the massive copper sulphide mineralisation are a mix of chalcopyrite $CuFeS_2$ and pyrite $FeS_2$, which were formed when sea water came into contact with molten magma (Figure 6.11).[813] These massive sulphide mineralisation beds form different minerals, and, under the action of percolating rainwater which reacts chemically with the primary ores (commonly called 'weathering'), produce 'secondary enrichment' oxidised copper hydroxycarbonate ores above the water table and sulphide ores below it (Figure 6.13a-b).[814] Figure 6.13c shows how the copper content of the ores is enriched throughout the secondary enrichment zone.

### Copper hydroxycarbonate ores formed above the water table

Above the water table, oxidation of the chalcopyrite $CuFeS_2/FeS_2$ pyrite mineralisation occurs through the action of rain and air, with the bacteria *Thiobacillus ferroxidans* acting as a catalyst.[815] This oxidation process is commonly

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[811] Knapp 1999a: 98-109, Knapp, Kassianidou and Donnelly 2001: 204-210, Gale 2001: 125-126, and Stos-Gale and Gale 2002: 358-362.

[812] Gale 1991: 43-57.

[813] For a very readable overview for the non-geologist of the role of tectonics in the formation of copper sulphide mineralization, with particular reference to Cypriot deposits, see Gale *et al* 1997: 87-89, Figure 2. For a more in-depth explanation of the geological processes which occur when sea water interacts with molten magma with or without an admixture of hypothermal fluids escaping from deep in the earth's magma, see Yang and Scott 1996: 420-423 and Wright and McCurry 1973: 116-125.

[814] The term secondary enrichment zone can be confusing, as some authors restrict this area to the area below the water table, and others to all modified ores above and below the water table. Hereafter secondary enriched ores will refer to both types of enriched modified ores. By the LBA in Cyprus most of the easily obtainable oxidised ores had been fully exploited in the EBA and MBA, leaving the enriched sulphide ores just below the water table as the main ore available for smelting.

[815] *Thiobacillus ferroxidans* is a member of the chemolithotrophic bacteria group which inhabit ore-bearing geological formations that are above the water table and exposed to air. They grow using the energy produced by the breakdown and oxidisation of ferric irons, pyrite, and colloidal sulphur within the ore. This process, called bacterial leaching, is used commercially for bioleaching base metals and the sector grew from a value of $2 billion worldwide in 1988 to $8 billion in 1998 (See Blake, Shute and Howard 1994: 3349-3357 for an in-depth research project on the chemical and bacterial processes involved).

called 'weathering'. The main ores formed in this process are the hydroxycarbonate ores: malachite $CuCO_3.Cu(OH)_2$, and azurite $2CuCO_3.Cu(OH)_2$.[816]

**Sulphide ores formed below the water table**

Copper sulphide ores were formed in those areas where oxygen was not available for oxidisation. Below the water table, where oxygen is excluded, the conversion process changes from a process of oxidation to a reduction process.[817] The common ores found just below the water table are bornite $Cu_5FeS_4$, chalcocite $Cu_2S$, chalcopyrite $CuFeS_2$, and covellite CuS, within a much larger matrix of unaltered Chalcopyrite $CuFeS_2$/Pyrite $FeS_2$.[818]

## Copper ores from Timna in the Arabah

The Timna Valley is 30 km north of the Gulf of Eilat, and the mining region itself covers an area of approximately 70 sq km. The topography of the mining region is semi-circular in shape, formed by wind erosion and occasional flash floods.[819] On three sides, to the north, west and south, the mining area is surrounded by steep cliffs up to 470 m high, while on the east side it is open to the Arabah Rift Valley. Copper mineralization occurred in sandstones, dolomites and shale beds across the valley floor and is found mainly in the form of nodules.[820] These nodules are partially

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[816] Ferrous sulphate in solution ($FeSO_4.4H_2O$) and sulphuric acid ($H_2SO_4$) both form in the 'weathering' zone and react together to produce ferric sulphate ($Fe_2.(SO_4)_3$). The resulting aqueous acid solution oxidises the chalcopyrite $CuFeS_2$ in the ore to form copper sulphate. Percolating rainwater passing through the upper layers leaches out the copper sulphate, forming a concentrated aqueous copper sulphate solution in the lower levels, which in turn reacts with carbon dioxide from the air, precipitating to produce malachite $CuCO_3.Cu(OH)_2$ and azurite $2CuCO_3.Cu(OH)_2$.

[817] Any remaining copper sulphate solution percolating down and reaching unmodified chalcopyrite $CuFeS_2$/pyrite $FeS_2$ exchanges the Cu ion from the copper sulphate solution with the Fe ion of the unmodified ore, causing the precipitation of various ferric sulphides, of which chalconite Cu2S and covellite CuS are the most common.

[818] During the glaciation period the water table dropped again in Cyprus, allowing a secondary oxidisation process to take place. With the lowering of the water table, iron-free copper sulphides and the secondary enriched ores reacted with the dry oxygen-rich conditions, which oxidised them to various copper oxide minerals, of which the most common were cuprite (red oxide), melaconite (black oxide), and tenorite.

[819] The manpower analysis uses Timna as the example for Ancient Egyptian copper mining. Two other areas had significant ancient mining operations, Serâbît el-Khâdim (Mumford 2006: 13-67) and the Eastern Desert (Lucas 1927: 164-165).

[820] Asael *et al* 2007: 241-242. Copper mineralisation occurred along two fault zones (Ilani, Flexer and Kronfeld 1987: 271, Figure 1). The first is the Dead Sea Rift Valley, in which Timna is located, and the other is the transversal shear zone running from Southern Israel to Jordan, in which the ancient mining centre of Feinon is located. The fault zones are conduits for water, probably saline, emerging from underground aquifers and/or volcanic hydro-thermal solutions. Copper mineralised intrusives

oxidised pyrite and chalcopyrite, forming complex mixes of azurite, chalcocite, and malachite ores. These oxidised ores and their associated silica gangue can be smelted directly with charcoal to form black copper.[821] In processing this avoids the necessity of preliminary roasting of the ores to produce copper matte prior to smelting, as is necessary with the sulphide ores from Cyprus. The nodules have a high copper content of up to 37%, and are most concentrated in the slopes leading up to the cliffs.[822] Small quantities of nodules are still found at ground level today, left there by millennia of flash floods that have eroded the ore-bearing rocks in the lower parts of the Timna cliffs and outcrops and deposited them on the valley floor. By the LBA most of this easily accessible supply had dried up after EBA and MBA smelting activity in the Timna area, and so it was necessary to dig down to the nodule-rich sandstone beds that lay below the surface.[823]

## Part 2: Excavation of copper and tin ores

In Cyprus the volume of sulphide ore which needed to be excavated to make one kg of refined copper has been estimated to be 0.0755 $m^3$ of ore.[824] Two types of LBA mines have been found in Cyprus, adits and open-cast mines (see again Figure 6.9). Adit mines were dead-end tunnels which entered the mountainside following the enriched sulphide ore veins.[825] Open-cast mines only required the removal of the gossan top cap to reach the enriched sulphide ores.

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and/or mineralised rocks carried by the water were deposited in the higher carbonate and/or conglomerate host rocks (Ilani, Flexer and Kronfeld 1987: 276).

[821] Koucky and Steinberg 1982: 178, endnote 42.

[822] Rothenberg 1972: 20. The copper sites at Feinan in Jordan have copper concentrates of 15-20%, which is much lower than at Timna, despite being composed of similar white sandstone beds containing mainly malachite nodules. Even this figure was achievable only after careful and time-consuming hand picking of the nodules to remove the gangue (Hauptmann, Gerd and Bachmann 1989: 8).

[823] The Timna site has been excavated extensively for over 40 years, much of that time under the direction of Beno Rothenberg. The survey and excavations at Timna known as the `Arava Expedition' have been sponsored by the Ha'aretz Museum of Tel Aviv, the Institute of Archaeology, Tel Aviv University, and, since 1974. the Institute for Archaeo-Metallurgical Studies of University College, London. For an overview of the site in general and the topography and geology in particular, see Rothenberg 1967: 53-70 and Rothenberg 1972: 18-20.

[824] The calculations and assumptions for the Cypriot Apliki sulphide ores are given in Report 6.1.2 in BRONZECALC. The methodology follows a similar analysis provided by Healy 1978: 195, based on estimates of slag to ore ratio of 1:1.2 associated with the Roman copper mines at Rio Tinto. Bear describes the ores from the Apliki district as porous and spongy in character with an average density of 2,265 kg/$m^3$ (Bear 1963: 46, 63).

[825] From the Roman period onwards, deeper mines leading to extensive galleries were possible, owing to improved ventilation and pumping technology to control flooding.

At Timna, a warren of tunnels and galleries radiated out from vertical shafts up to 30 m deep (see again Figure 6.10).[826] Steps were cut in the sides of the access shafts for the miners to climb up and down the tunnel shaft (Figure 6.16).[827] The soft sandstone rock was easily excavated, with bronze sockets fitted to wooden shafts (Figure 6.17).[828] The volume of nodule ore and gangue which had to be excavated to make one kg of unrefined copper is estimated as 1.19 $m^3$.[829] The need to excavate such a large volume per kg of copper produced in Timna is due to the quantity of gangue removed from the tunnel. Ergonomically the tunnel dimensions had to fulfil three functions; to be large enough for a miner to lay flat but still use the tools to extract the ore, to follow the undulating nature of the ore veins, and finally to allow the excavated ore and gangue to be passed back by the miner for another worker to remove the ore to the tunnel shaft (Figures 6.18-6.19). With narrow ore veins much of the effort expended by the miners was therefore related to the removal of gangue, which had to be pushed back under the face worker to a collector behind (Figure 6.20).[830] Figure 6.21 illustrates how much gangue had to be removed, even when the ore band was thick.

Similarly, the tin trench mines in Uzbekistan also required significant waste gangue to be removed along with the ore. The miners dug vertical trenches, sometimes with bridges of original rock left for stability, and some of these were at least 30m deep (Figures 6.22-6.23). The cassiterite ore vein was on average only 0.075 m thick, but required a trench 0.6 m wide for the miner to follow the vein downwards. The tin content of the ore from one part of the mine measured 4%.[831] The volume of ore and

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[826] Conrad *et al* 1980a: 69-91.
[827] Conrad *et al* 1980b: 157-167.
[828] Conrad *et al* 1980a: 83-85.
[829] The calculations and assumptions for the Timna mines are given in Report 6.1.3 in BRONZECALC. The Timna tunnel measurements are taken from site 27 at Timna and the field study assessment of the ratios of ore to gangue from Bartura, Hauptmann and Schone-Warnefeld 1980: 41-56, particularly Figure 20. The tunnels ranged from 0.5-1.5 m high and 0.3-0.6 m wide. The tunnels of the exhausted veins were backfilled to minimise the quantity of gangue that had to be lifted to the surface. Some of the tunnel complexes were accessed by vertical shafts up to 36 m in depth (Conrad and Rothenberg 1980: Supplement 11).
[830] The veins of ore nodules range typically between 5 to 25 cms in depth, between layers of gangue typically 0.3-0.5 m apart, and in the longitudinal direction the veins ranged between 50-300 m in length, but were discontinuous with stretches of red Nubian sandstone (Rothenberg 1962: 9-10).
[831] Cierny and Weisgerber 2003: 26. The authors considered 2% was a more appropriate output analyses from this site and this assumption has been used in BRONZECALC (Cierny and Weisgerber 2003: 27).

gangue for this type of mine required 0.0571 $m^3$ to be removed to produce one kg of tin.[832]

## Part 3: Mining copper and tin ores

The number of variables involved in the mining process is numerous, and each of these influenced the time taken to extract the ore: the cross-section of the ore vein, the depth of the mine, the stability of the surrounding rock, the need for ventilation for the miners, and the depth of the water table.[833] The limitations of LBA mining technology prevented ancient Cypriot miners from extracting ore from the deep mass of sulphide deposits, and ventilation and dust problems in particular limited the length and depth of the tunnels at Timna. The open trench system used to mine tin in central Asia was limited to the depth of the water table to avoid flooding.

### Extraction rates of ore and gangue

This section uses three pieces of evidence to calculate extraction rates.[834] The first is a text which describes the digging of the Egyptian Eighteenth Dynasty Tomb of Senenmut (ca. 1473-1458 B.C.).[835] A hieratic ostraca currently in the Metropolitan Museum of Art outlines the work record of a day's work carried out by eleven masons excavating his tomb. It shows that in a day the masons progressed one rod in depth (0.65 m), 6 rods in width (3.9 m), and one cubit into the tomb (0.52 m). This means that 1.319 $m^3$/day of limestone was removed by eleven masons. From an ergonomic perspective the number of masons who could physically work together in

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[832] See Report 6.14 in BRONZECALC.

[833] The problems of ventilation can be easily demonstrated using statistics from the U.S. Department of Health. Assuming a Timna tunnel was 0.6 m × 0.6 m × 20 m, the volume of air would be 7.2 $m^3$. If two men were working in the tunnel (one pit face worker and one man to clear the excavated rock and gangue), the workers would start to suffer physiological impairment within 24 minutes, and this would be exacerbated by the use of naked torches (Kyriaz 2006).

[834] Of all the calculations described in Chapter 3, there is the least direct evidence regarding the manpower required for excavation.. Unlike the other parts of the process which are underpinned by archaeological, experimental archaeology, ethnographic and textual evidence, there is a lacuna regarding this activity. After extensive research the author has found only three pieces of evidence applicable to pre-industrialised mining. It is recommended that this topic should be considered a high priority for future experimental projects if we are to truly understand mining resource requirements in antiquity.

[835] Hayes 1942: 21. The tomb is situated near the top of the Theban North 'Abd el-Qurna necropolis, and the limestone bed where the tomb was constructed is of a more friable nature than the southern necropolis at 'Abd el-Qurna (Manniche 1987: 11 and Porter, Moss and Burney 1960: 140-142, Figure 5). This would give a reasonable approximation of the effort required for extraction of the soft sandstone mined at Timna.

a width of 3.9 m would be a maximum of only five, and presumably the other six took it in turns to remove the spoil. This means that one mason could remove 0.264 $m^3$/day. However, the cramped conditions and poor ventilation would have seriously inhibited mining at Timna, and the rate has been halved to give an extraction rate of 0.119 $m^3$/day.[836]

The second piece of evidence is based on analysis carried out by Ardaillon while investigating the Greek silver mines at Laurion.[837] This evidence is frequently quoted in studies of mining in antiquity[838]. Ardaillon estimated that in a tunnel measuring 0.6 m by 0.8 m, with one man at the tunnel face digging, the tunnel would progress by on average 0.011 m a day. This equates to a very low rate of progress, up to a maximum of 0.00396 $m^3$/day. This analysis has been rejected as not being relevant for the mining of copper ore at Apliki or Timna, as the ore-bearing rock surrounding the argentous lead veins was very hard compared with the gossan cap covering the sulphide ores from open-cast mines at Apliki and the sandstone bedrock at Timna. However, the analysis does seem more relevant for estimating mining activity in central Asia, where the granite/quartz rock matrix appears similar to that described for Laurion.[839] The Ardaillon analysis will be used for tin ore extraction, and the additional workload associated with providing wood for firesetting will be included in analysis of the Uzbekistan trench mine (Figures 6.22-6.23).[840] Experimental archaeology studies of firesetting have demonstrated that the ratio of rock removed to the weight of wood used is in the ratio 1 to 0.62 (Figure 6.24).[841]

The third piece of evidence uses the digging rate used the work-study data measure from the Overton Down experiment in Wiltshire, where a chalk ditch was dug in

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[836] The full analysis is given in Report 6.2.1 in BRONZECALC.
[837] Ardaillon 1897: 25-26.
[838] Examples are Macdonald 1961: 19-21, Hopper 1968: 293-326 and Conophagos 1980: 168-198.
[839] Cierny and Weisgerber 2003: 24-27 for Central Asia and Hopper 1968: 293ff.
[840] Cierny and Weisgerber 2003: 26 and Figure 6. Firesetting is a technique used to crack rock by inducing thermal stresses from a wood or charcoal fir at the rock face. Fires were lit against the ore-bearing rock face until hot, and then doused with cold water. The resulting thermal shocks caused by sudden contraction caused cracking, which facilitated removal with pickaxes. Firesetting gives a characteristic concave shape to the mining tunnel (Timberlake 1990: 49-54). For textual evidence of firesetting in antiquity, see Pliny, *NH.* 23.21 and Diodorus Siculus, *Bibliotheca Historia.* iii. 12.4.
[841] Py and Ancel 2006: 78, Figure 4. The ratio is the average of sixty-six experiments replicating ancient firesetting practices at the medieval Fournel silver mines in the Hautes-Alpes, France. This figure will be used in calculating the additional manpower for lumbering and transporting the wood to the mines in Report 6.2.5 in BRONZECALC.

chalk with the same geometric profile as that forming the Avebury Henge.[842] This evidence is used specifically for the Cypriot LBA mining activities. Concrete evidence for LBA mining activity is rare in Cyprus but the close proximity of the enriched sulphide ore outcrops on the pillow lava slopes to the surface make open-cast mining from an ergonomic perspective a likely option. The sulphide beds in the weathered zone of sulphide ores along the northern edge of the Troodos Mountains have a gossan cap that can be up to 3 m thick, and this gossan cap and the relatively soft sulphide ores can be easily removed by open-cast mining using primitive tools.[843] The Overton Down results shows that a fit adult man could excavate on average 3 $ft^3$/hr/man (0.0849 $m^3$/hr).[844] Taking into account differential densities of materials dug and the length a time that an adult could sustain this rate, the digging rate of an open-cast mine would be approximately 0.08 $m^3$/day/man.

The Cypriot outcrop mines would have been considerably more difficult than the open-cast pits at Apliki. One example where a Bronze Age mining context still remains is the Ambeliko-Aletri mining complex, to the west of Apliki but located on the northern pillow lavas of the Troodos Mountains.[845] The mine tunnel complex and galleries have similar characteristic to Timna.[846] The volume of gangue which had to be removed would have been greater than in the open-cast mines at Apliki, where only the gossan had to be removed before reaching the weathered sulphide ore. Greater effort would also have been needed to lift the excavated ore up the tunnel shaft. Ventilation and dust would not have been as extreme as the heat and dust pollution experienced in Timna, but any benefit of lower temperatures may have been outweighed by pockets of sulphurous fumes. After balancing these variables, the removal rate for mines is assumed to be the rate used for Timna, ranging up to 1.19 $m^3$/day/man.

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[842] Jewell 1963: 50-64. The purpose of this experiment was to see the infill of the ditch caused by rain and wind and then to use this data for the analysis of Avebury and other Neolithic excavations in the UK. The opportunity was taken to carry out controlled work-study of the excavation process using replica tools excavated at the Avebury site, made of animal scapula bones and antler picks.

[843] Bear 1963: 63 and Constantinou 1982: 23.

[844] The calculation and assumptions are given in Section 6.2.4 in BRONZECALC.

[845] Merrillees 1984: 1-13. The complexity and undulating nature of the workings are clearly shown in Merrillees 1984: 10, Figures 5 and 12.

[846] These mines typically had adits, which were dead-end tunnels which entered the mountainside, and they also had deep-vein mines accessed by interconnecting shafts and radiating tunnels and galleries, similar to those at Timna.

### Mining manpower requirements

The man-days required to carry out the mining activity can be calculated using the volume of ore extracted to make 1 kg of tin or copper from Section 6.2.1 and the ore extraction rates above. The number of days to dig and remove the ore in the Timna mine can be calculated, whereby the minimum number of days worked to mine 1 kg of copper ore at Timna equals the volume of ore taken from Timna to make 1 kg copper 1.19 $m^3$ divided by the volume of ore removed by one Timna miner 0.119 $m^3$/day, giving a result of 10 days. Each miner was supported by different numbers of workers, depending on the type of mine and location.[847]. For the Timna example, the miner was supported by a team of 8 workers, who were responsible for removing the ore and gangue from the mine.[848] The minimum man-days expended would therefore be $9 \times 8 = 72$ days. Similarly, the total number of days required removing the 0.0755 $m^3$ of Cypriot copper sulphide ore to make one kg of copper is 4.5 days, and the total number of days required to remove the 0.0571 $m^3$ of tin ore from Uzbekistan to make one kg of tin is 86.4 days. The man-years to extract the equivalent copper and tin ingots found on the Ulu Burun wreck are shown below.

| Ore extraction man-years | | |
|---|---|---|
| Copper | | Tin |
| Cyprus | Timna | Central Asia |
| 153 | 2,722 | 281 |

**Table 6.1: Manpower required to extract sufficient ore to make the copper and tin ingots found on the Ulu Burun wreck**

The tabulated results clearly show that the manpower required for mining copper ore in Cyprus is significantly lower than at Timna or for the tin mined in central Asia. The next section will now calculate the manpower required to prepare the excavated ore for smelting.

## 6.2.2 Preparation of ores for smelting

### Beneficiation

The term beneficiation is used for the process of removing gangue from the ore to enrich its metal content and so to maximise the efficiency of smelting. It will be shown later how valuable charcoal was as a commodity, and therefore the need to

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[847] See Report 6.2.1 in BRONZECALC.
[848] Conrad *et al* 1980a: 93-94.

avoid heating worthless gangue became an imperative. The evidence from Timna shows that the first stage of beneficiation consisted of minimising the need to remove worthless gangue from the mine by backfilling previously exhausted tunnels and galleries.[849] The next stage was an initial hand sort to remove the obvious gangue from the ore, and the 'tailings' (i.e. rejected lumps of discarded gangue) from this hand sort are still to be found today in many ancient mining/smelting sites.[850] The concentrated mixture was ground and hammered into small 4-5 mm pieces using tools such as those from site 39 at Timna shown in Figure 6.25.[851] *Agricola* suggested that if ore was heated prior to the beneficiation, the differential expansion in the rock would generate fissures that assist fragmentation when crushed.[852] The final stage was winnowing, throwing ore and gangue into the wind, and thus causing the heavier ore to separate from the gangue.[853] The scale of the beneficiation process carried out in Cyprus is clearly seen in the spoil heap, which was 9.5 m high in the ancient mine at Agrokipia *Kriadis* (Figure 6.26). The heap was composed of crushed ore of fairly uniform pea size and fines, both consistent with the product of ore beneficiation.[854]

Merkel examined tailings at the Egyptian Timna site and replicated the beneficiation process, showing that the copper content of ore that had been through a preliminary hand sort could be increased from an overall 12% to a maximum of 30%, the average being 24.75%. The resulting tailings had as little as 1.35% copper metal content. Merkel's experimental archaeology of the beneficiation process highlights the labour

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[849] Drenka 2003: 23, Jovanovic 1980: 34, Lewis 1990b: 5-10, and Shaw 1995: 296-297.
[850] By convention, tailings is the name given to these lumps of discarded gangue.
[851] Rothenberg 1972: 229-230 and Tylecote and Boydell 1978: 43-44.
[852] Hoover and Hoover 1950: 273. *Agricola* wrote a number of books concerning a range of metallurgical matters that provide an invaluable insight into pre-Industrial Revolution techniques. His most famous work is *De Re Metallica* of 1556. Doonan carried out an experiment to see if *Agricola*'s suggestion would lead to a productivity increase in the beneficiation process. The result proved even too successful, because grinding the heated nodules created a large proportion of 'fines' (very small particles of ore) that would have been blown out of LBA furnaces from the forced draft created from the bellows (Doonan 1994: 85).
[853] Doonan 1994: 84-85 lists evidence from sites in Peru, Austria, the Great Orme in Wales, Laurion, and Timna in the Sinai showing that ancient gangue waste piles indicated that very little copper remained. Willies 1990: 15 carried out winnowing experiments on crushed ore found on the site of the Wadi Amram mines in the Sinai, and his experiments show that the prevailing winds were sufficient to make this an effective operation.
[854] Given, Knapp and Coleman 2003: 64-67, Figures 4.3-4.4. For discussion on the difference between mining debris and the product of ore beneficiation, see Craddock 1989: 187.

intensive nature of the process (Figure 6.27).[855] Koucky and Steinberg's, and Raber's, findings are more pessimistic than Merkel's, proposing 12% as a realistic average of enriched ore after beneficiation.[856] This 12% figure is supported by Doonan's beneficiation experiments, which sorted and crushed 150kg of 'as mined Chalcopyrite sulphidic ore' and produced 33.4kg (22.27%) of enriched ore with an average copper content of 11.5%. Doonan's work-study of the process took 42 man-hours, representing an average production rate of 0.8 kg/hr enriched ore.[857] This rate has been chosen for the manpower requirements for beneficiation in BRONZECALC.[858] The analysis shows that to collect, hand sort, grind and winnow the 78.4 kg of ore required to make one kg of copper would take 98 days.

## Roasting Cypriot copper sulphide ores

The sulphide ores from Cyprus required an additional roasting process compared to the copper-bearing nodules from Timna. This process removes excess sulphur, which is bound to the copper in the Cypriot ores and released in the form of sulphur dioxide $SO_2$. For chalcopyrite ($CuFeS_2$), mixed with iron pyrite $FeS_2$, the most common ore in Cyprus, a number of chemical reactions occur, depending on the length of roasting time and the operating temperature. The chalcopyrite and iron pyrites are converted into sulphides of copper and iron and release sulphur dioxide $SO_2$ as fumes, and this process is commonly called matting.[859]

$$CuFeS_2 + 5O_2 + 2FeS_2 \rightarrow CuS + FeS + 2FeO + 4SO_2$$

If the copper matte is roasted further, a mixture of copper and iron oxides are produced which can be more easily smelted. The chemical reaction is:

$$CuS + FeS + 3O_2 \rightarrow CuO + FeO + 2SO_2$$

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[855] Merkel 1985: 164-169. Merkel's results may have been optimistic, as the nodules were not excavated but collected from the surface. These nodules would have been naturally weathered by the action of wind and occasional rain, which would have removed most of the gangue normally attached to excavated ore. Unfortunately the total time for the beneficiation was not recorded, as this was not the objective of Merkel's experiments. Merkel points out that it was an arduous task using replica stone tools, so they resorted to modern tools to complete the experiment.
[856] Koucky and Steinberg 1982a: 162-173 and Raber 1984: 204-212.
[857] Doonan 1994: 86-87. See Doonan 1994:Table 3 for the complete analysis of the beneficiated ore.
[858] See Report 6.3.1 in BRONZECALC.
[859] There is a partial roasting stage for both chalcopyrite and pyrite prior to the reactions shown below, known as partial roasting. The chemical reactions for chalcopyrite being $4CuFeS_2 + 7O_2 \rightarrow 2Fe_2O_3 + 4CuS + 4SO_2$ and for pyrite being $4FeS_2 + 11O_2 \rightarrow 2Fe_2O_3 + 8SO_2$ (Craddock 1995: 149).

Once alight, little additional fuel is required, as at 400˚C the chalcopyrite itself starts to burn from the sulphur within it, creating a self-sustaining exothermic process where charcoal is not necessary.[860] Doonan replicated ancient roasting processes based on the evidence of roasting pits excavated in the Ramsau in the Upper Enns Valley in the eastern Alps.[861] Beneficiated chalcopyrite was roasted in a pit varying the airflow, firing conditions and the way the ore was introduced to the pit fire. The copper to sulphur ratio for pre-roasted beneficiated chalcopyrite was 1.36 to 1, and after roasting, the copper to sulphur ratio increased up to a maximum of 2.56 to 1. This was achieved using a fuel to ore ratio of 1:8 by weight.[862] The manpower required for cutting the timber, transporting the wood by donkey to the roasting site, and monitoring the roasting process is low. The manpower to make 1 kg is so small as to make a day rate comparison with other parts of the bronze-making process meaningless. It would be more meaningful to determine the manpower that would be expended in roasting the ore required producing the 10 tons of copper from the Ulu Burun wreck, and even in this case the roasting process would still only be up to a maximum of 21 man-years.[863]

## 6.2.3 Smelting

This section discusses the smelting processes used in the LBA and the manpower requirements to support it. At its simplest, smelting is the separation of metal from its oxides, gangue or other undesired metals within the ore, and in the process a slag is formed containing all unwanted material, which can then be removed.[864] The molten copper separates from the slag because copper has a higher specific gravity and a lower viscosity than the slag, thereby falling by gravity to the floor of the furnace.[865] The free-flowing nature of the resulting combined molten flux and gangue has the

[860] Atzeni 2005: 19, Horne 1982a: 8, and Koucky and Steinberg 1982a: 165.
[861] Doonan's roasting experiments show how dangerous it must have been for ancient workers: "….. the sulphur dioxide emitted from the roasting ore was very intense; even some 200 metres away the smell of the sulphur dioxide was intense enough to cause a noxious sensation" (Doonan 1994: : 90).
[862] Doonan 1994: 89-92.
[863] The assumptions, references and calculations are fully covered in Reports 6.3.2-6.3.4 in BRONZECALC.
[864] Charles 1980: 153.
[865] Atzeni 2005: 18. The specific gravity of copper in relation to gangue is 0.875 g/cm$^3$ to 0.75 g/cm$^3$. The viscosity of molten copper and gangue is 0.75 cPoise and 0.25 cPoise. As a comparator, water has a specific gravity of 1 g/cm$^3$ and a viscosity of 1 cPoise.

additional benefit of reducing the time taken to tap the furnace and therefore decreasing the total elapse time to smelt a given quantity of ore.[866]

Smelting removes oxygen from the copper ore in a reducing environment. The simplest illustration of the smelting process is the reduction of copper oxide (CuO), where two main chemical processes take place.[867] A reducing environment is created when carbon monoxide (CO) is formed in the furnace or crucible under conditions where there is insufficient oxygen to form carbon dioxide ($CO_2$).

$$2C + O_2 \rightarrow 2CO$$

In parallel with this, the carbon monoxide combines with the oxygen in the copper oxide to form copper and carbon dioxide, which escapes with the flue gases. The chemical reactions are:

$$CuO + CO \rightarrow Cu + CO_2$$

## 6.2.4 LBA furnace designs

A brief overview of the design of LBA furnaces follows, and the rationale is explained for the assumptions that have been made in assessing the manpower required to smelt the copper ores. The design of ancient furnaces and smelting crucibles differs from pottery kilns as the fuel has to be in close contact with the ore in order to produce reducing conditions. In general, pottery kilns have the fire at the entrance or bottom of the kiln in a horizontal firing chamber quite separate from the pots. The consequence of this is that the smelter has less control than the potter once the furnace is fired.[868]

Merkel has carried out a wide range of experiments which have replicated Ancient Egyptian smelting processes, basing his design of furnace on the remains of shaft

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[866] Analysis of ancient slag from Cyprus shows that siliceous flux had been used at Kalavassos, while at Skouriotissa and Lefkara manganese oxides were used. Manganese oxide has the advantage over siliceous flux in that it removes any iron produced in the smelting process, which would otherwise contaminate the copper smelt (Bachmann 1982a: 148-149). Conversely, if the ores contained an excess of silica through poor beneficiation, the reverse was performed by adding iron oxide. Craddock 1995 : 130 and Tylecote 1980c: 183-184.

[867] This illustration is a simplification, as the ore charges that would have been fed into LBA furnaces would not have been pure copper oxide. Roasted Cypriot chalcopyrite ores would have been a complex combination of copper oxides and hydroxycarbonates, incomplete roasted ore, copper and iron sulphides, and residual gangue. The Timna nodules were equally complex mixtures of pyrite, chalcopyrite, malachite, chrysocolla, chalcocite, and residual gangue (see earlier discussion 6.2.1).

[868] Bamberger 1985: 151-157 and Tylecote 1962: 65.

furnaces at sites 2, 30, and 39 at Timna (Figures 6.28-6.32).[869] The shaft furnaces was 0.5 m at one end rising to ground level at the other, and 1.8 m in length, and lined with clay (Figures 6.29-6.30).[870] The tapping point was 0.1 m above the furnace bottom, allowing the hot liquid slag to flow quickly into the slag pit.[871] Two tuyères were fitted, one at the rear and one at the front, though there may have been more (Figures 6.31-6.32).[872] A tuyère was a 0.1 m clay tube fitted into the back of the furnace, into which was placed a 0.003 m clay tube with a nozzle of clay to minimise the effects of heat from the furnace conducting back along the pipes to the bellows.[873] They were probably attached to foot bellows, as depicted in the tomb scenes of Rekhmire (Figure 6.33).[874] Merkel's field experiments found that three bellow-operated tuyères gave adequate air flow for successful smelting (see again Figure 6.28).[875]

## 6.2.5 Manpower requirements for the smelting process

To determine the manpower requirements for smelting, BRONZECALC uses the results of experimental archaeology carried out on LBA furnaces by Merkel and Tylecote.[876] Tylecote's smelting experiments show that sulphide ores could not be smelted in crucibles unless they had been pre-roasted to convert the sulphide ore into copper oxide.[877] Metallurgical analysis of the ingots found on the Ulu Burun wreck

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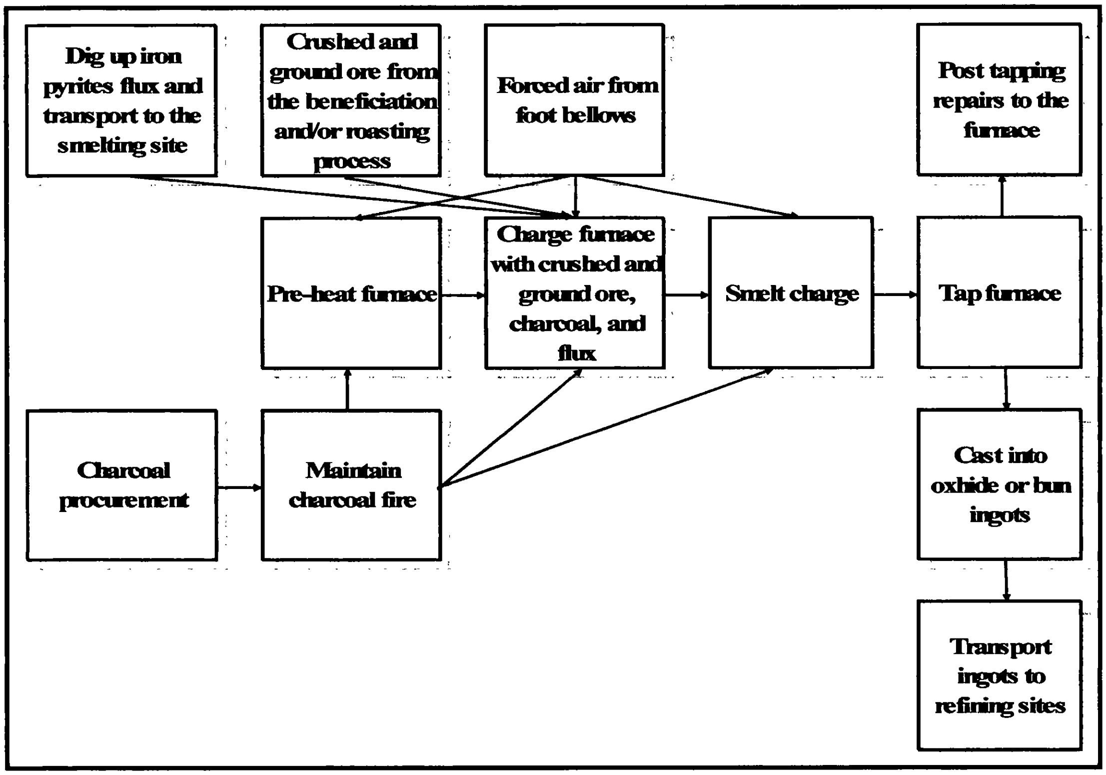
[869] Merkel 1983a: 173-178, plate 2, Merkel 1983b, Merkel 1985: 164-169, Merkel 1989: 217-234, Merkel 1990: 78-122, Merkel 1995: 79-87.
[870] Rothenberg 1972: 72-74.
[871] Rothenberg 1972: 72-74.
[872] The LBA tuyère was a pipe of clay that allowed the forced air from the bellows to pass into the furnace.
[873] Rothenberg 1972: 75, Figure 20 shows the build-up of slag formed around the cold spot created by the air entering the furnace from the bellows.
[874] Wall scenes from the tomb of Rekhmire show how bellows and tuyères were used in practice (Davies 1973: Plate LII). For a more in-depth discussion on the design and development of the Egyptian combined tuyère and bellow-forced draught systems, see Nibbi 1977: 59-60 and Tylecote 1981: 107-118. For archaeological evidence, see Davey 1979: 101 for bellows found in Northern Syria (after Beit-Arieh 1987: 62, Plate D) that show a New Kingdom Egyptian bellow excavated in Mine L at Serabit el-Khadim in the Sinai. Albright 1936-1937: 136, Plate 40 shows two bellows of similar design excavated from stratum D of the Middle Kingdom site at Tel Beit Mirsim.
[875] Bamberger and Wincierz investigated the optimum number of tuyères based on the Timna designs. They found that with three tuyères the combustion of the charcoal was incomplete in some parts of the furnace, and that this became a trap for slag and copper. They suggested more tuyères would have been necessary to minimise this problem (Bamberger and Wincierz 1990: 131).
[876] Merkel 1983a: 173-178, Merkel 1983b: 159-262, Tylecote 1980a, Tylecote and Boydell 1978: 27-51.
[877] Tylecote 1974: 54

has shown that they were made from sulphide ores.[878] It has therefore been assumed in the smelting manpower analysis in BRONZECALC that shaft furnaces rather than crucibles were the preferred choice of furnace. Three process stages are evaluated: procuring flux, the smelting cycle itself, and the building and post-smelting repairs to the furnace.[879] The smelting process is shown in the schematic below:




**Schematic 6.2: The LBA smelting process**

## Manpower required for the procurement of flux

The most common flux in the LBA was iron pyrites, and manpower was expended digging it up and transporting it to the smelting site. The latter activity would have been minimal, as iron pyrites would have been available in close proximity to the Cypriot and Timna smelting sites. The ratio by weight of iron pyrites to copper ore for a successful smelt was approximately 3:1.[880] With an ore charge of 78.4 kg, required to make one kg of copper, the requirement for flux to be dug out would have been 235 kg.[881] Using this extraction rate, it is calculated that to dig sufficient flux to

[878] The metallurgical and chemical composition of LBA ingots is discussed in more detail in Appendix 3, Section 3.1.
[879] See Reports 6.4.1-6.4.4 in BRONZECALC.
[880] Merkel 1985: 226-227.
[881] It has been assumed that the work study for the time taken to excavate chalk in the Overton Downs experiment discussed in Section 6.2.1 can be applied to the excavation of iron pyrites, because the

smelt the copper required to make the copper ingots on the Ulu Burun wreck would have required up to 1,027 m$^3$ of flux. This would call for approximately five man-years of effort.

## Manpower requirements for smelting copper

### Data based on experimental archaeology studies

Despite the beneficiation process, some gangue would have been present in the ore and charcoal (hereafter charge) fed into the furnace. Experiments by Tylecote using a furnace design based on those found in LBA contexts at Timna indicate that the separation process requires time to allow the copper to sink to the floor. His experiments showed that six hours were required to heat up the furnace, 1.5 hours for the smelting and a further 1.5 hours to allow partial separation of the copper.[882] It has been assumed that the elapse time for a successful smelt is one day, assuming an eight-hour day. Experiments using an Egyptian-style bellow/tuyère-forced drafting system from Timna show that a minimum of three tuyères were required, and they required three men plus a fourth to provide the a rest for the other three bellow operators in turn.[883] In addition, one man was required to charge the furnace with additional charcoal to maintain the temperature, giving a total of five men per furnace. The smelting of sufficient copper to produce the copper ingots on the Ulu Burun wreck would have required up to 155 man-years of effort.

### Maintenance manpower required for building and repairing shaft furnaces

Experimental archaeology has shown that the action of the intense heat and slag caused damage to the clay and sand refractory lining of the furnace, particularly around the tuyères.[884] It was also necessary to extract copper prills remaining within

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densities and compaction characteristics of iron pyrites and chalk are similar (2400-2500 kg/m$^3$ respectively).

[882] Tylecote 1980a: 5-12. Merkel highlighted this problem when he replicated Tylecote's experiments using Sardinian oxide ores, which resulted in only 73% separation after six hours sustained heating (Merkel 1984: 152-157).

[883] The experiments of Merkel 1985: 176, Stocks 2003: 64-66, and Wendrich and Kooij 2002: 111. Bamberger 1985: 157 show that a minimum of 250 litres per minute is required for a successful smelt. Merkel's field experiment shows this was easily produced using two pot bellows, which had leather tops with two valves producing 350 litres of air per minute (Merkel 1985: 176, plate 2). For the operation and design variations of foot bellows, see Davey 1979: 101-111.

[884] Merkel 1989: 218 and Merkel 1989: 228, figure 6. 'Slagging' is the term commonly given to this form of attack. Merkel's experiments, based on evidence from the Timna furnaces, used a refractory mix made up of 95% quartz sand and 5% bentonite clay. Some additional form of protection from

the furnace, and this meant that to some degree the furnace had to be repaired following each smelt.[885] In antiquity, the ratio of ore to flux could not be controlled accurately, due to the varying grades of material available to the smelters. This would have resulted in a wide variation in refractory loss. This thesis has estimated that the time taken for repairs and a significant rebuild after every 10 firings has been estimated to be 1-2 man-days.[886] Using this rate, the manpower required to repair the furnaces required to smelt the copper ingots on the Ulu Burun wreck is estimated to be 62 man-years.

In summary, the manpower required for all three operations leading to the smelting of one kg of copper, and to smelt sufficient copper to produce the Ulu Burun wreck copper ingots is shown below.[887]

| | Maximum | |
|---|---|---|
| No. of smelts required to produce the copper ingots on the Ulu Burun | 9,525 | |
| Total man-days required to smelt one kg of copper | 7 | man-days |
| Total man-days required to smelt the copper ingots on the Ulu Burun | 68,376 | man-days |
| **Tot. man-years req'd to smelt the copper ingots on the Ulu Burun** | **222** | **man-years** |

**Table 6.2: Manpower required for the complete copper smelting process**

## 6.2.6 Smelting tin ores

Some evidence of the process used to smelt tin is to be found in archaeological records at Göltepe, an EBA site in Anatolia.[888] The evidence suggests that smelting of tin was done with a crucible furnace rather than shaft furnaces. As with copper smelting, the limited primary evidence has been supplemented through the use of experimental archaeology. Timberlake's experiments used a primitive furnace design based on the flat ceramic bowls excavated in Göltepe (Figure 6.34).[889] Finely ground cassiterite was added to a hole poked into the centre of a bed of burning charcoal, and the smelting was completed 1.5 hrs after charging the furnace with ore. The smelting temperature was reached and maintained using clay tuyères. A small lump

slagging was achieved by mixing the refractory clay and sand mix with charcoal dust in a ratio of 3:1, which provided some degree of insulation, particularly at the furnace hot spots around the tuyères (Merkel 1989: 220, 226-232).

885 Merkel 1989: 219-234.

886 Merkel 1989: 227 found that after ten smelts using the Timna shaft furnace design from site 2, 28 kg of refractory material was lost.

887 For the full analysis which also includes an analysis using the lowest values of assumptions, see Reports 6.4.1-6.4.4 in BRONZECALC.

888 Muhly 1993: 239-253, Yener and Vandiver 1993a: 207-238 and Yener, Vandiver and Willies 1993b: 255-264.

889 Timberlake 1994: 125, Figure 6.

of very pure tin formed on the underside of the furnace bottom, with a purity higher than 99%. Tin prills were also found within the slag matrix, which could be easily have been extracted by grinding and hammering with a stone on a stone anvil.[890] Earl, Timberlake and Tylecote's experiments suggest a temperature of 1100°C was necessary for successful smelting of cassiterite in antiquity.

Analysis of the manpower required for smelting tin is provided in Report 6.4.5 in BRONZECALC, which uses in the main the estimations derived from the experimental study of smelting cassiterite ore ($SnO_2$) by Timberlake.[891] The reductive environment is produced by ensuring the charge is covered by charcoal, and the cassiterite ore can be smelted in a simple crucible in one cycle using one tuyère, without any need for further refining. Only two men were required to smelt 1 kg of tin, compared with five men to smelt 1 kg of copper, reflecting the relative ease of smelting an oxide ore compared with a sulphide ore. Based on Timberlake's experiments, the time to complete one smelt from pre-heating of the furnace to extraction of the tin prills from the crucible furnace was 2.75 hrs.[892]

The manpower requirements to smelt 1 kg of tin and the manpower to smelt the tin ingots from the Ulu Burun wreck are given in the Table below:

| | | |
|---|---|---|
| No. of smelts required to produce the 1000 kg of tin on the Ulu Burun | 12,500 | |
| Total man-days required to one kg of tin | 8.6 | man-days |
| Total man-days required to smelt the tin ingots on the Ulu Burun | 8,594 | man-days |
| **Total man-years to smelt the tin ingots on the Ulu Burun wreck** | **28** | **man-years** |

**Table 6.3: Manpower required smelting 1 kg of tin and the total tin ingots on the Ulu Burun wreck**

It may have been the case that larger crucibles were used for tin smelting in the LBA than those used in Timberlake's experiments, which were based on the EBA Göltepe design. Timberlake achieved a maximum recovery of 0.128 kg of tin, compared with Merkel's experiments which recovered 1.1 kg of black copper.[893] Any increase in tin recovery for the same manpower would increase productivity. Further research using experimental archaeology to determine the optimum crucible size for operating

[890] Timberlake 1994: 122-126.
[891] Timberlake 1994: 121-130.
[892] Timberlake 1994: 124.
[893] Timberlake 1994: 125 and Merkel 1989: 222-223, Table 1.

manpower requirements would make a valuable contribution to our understanding of LBA tin production.

## 6.2.7 The production of bronze

The purpose of this section is to review evidence of the LBA production processes used to make bronze and to quantify the manpower required to support these processes. Two processes were involved: refining the smelted black copper to remove contaminants, and the alloying of copper and tin to make bronze. The quantitative analysis is given in full in Module 6 of BRONZECALC.

### The refining of copper to remove contaminants

Black copper is the term given to the unrefined product of smelting sulphide ores. Analyses of LBA black copper ingots and other ingots produced by experimental archaeology replicating LBA smelting processes show a high level of contaminants. The principle contaminants were iron and sulphur, and oxides, trace metals, residual flux and slag inclusions are all found in varying quantities depending on the success of the smelting operation.[894] Out of these, the highest level of contaminant smelted from sulphide ores was iron, which entered the copper melt from the iron pyrites flux.[895] As a result, black copper was brittle and porous with poor mechanical properties, making it unsuitable for tools and weapons that required work-hardened cutting.[896] Refining of copper was therefore an essential process if the artefacts made from the resulting bronze were to have any practical value.

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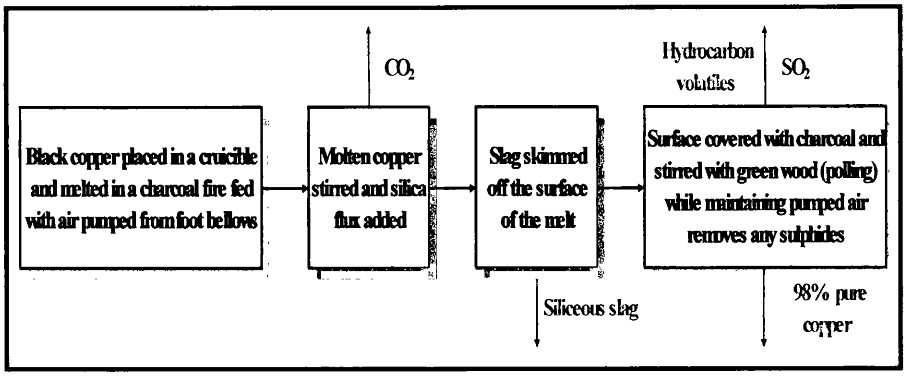
[894] The sulphur in the melt is chiefly in the form of copper sulphide $Cu_2S$ (Atzeni 2005: 22).
A characteristic of ancient metallurgical processes is the variability of the chemical composition of the ores and flux used in the smelting process. It was not until the Industrial Revolution, with the coming of better assaying of ores and flux, before any true quality control was introduced. See Tylecote 1980b: 204, Figure 7.6 for the variability of the chemical composition of slag for different periods from the Chalcolithic period up to the Iron Age.
[895] Merkel 1985: 226. Copper produced from Timna ores typically contained between 10-25% iron in the copper that had flowed to the bottom of the furnace. Any copper prills trapped in the upper part of the shaft furnaces generally had lower levels of iron. (Tylecote 1980a: 5).
See Craddock 1980: 165-173 for the composition of copper smelted at Timna and Tylecote 1977: 317-336 for Cypriot copper. For a more general metallurgical review of copper, see Sperl 1980: 212-217. See Bachmann 1982a: 143-151 and Zwicker, Grembler and Rollig 1977: 309-316 for slag inclusions. See Cooke and Aschenbrenner 1975: 251-266 for occurrence of metallic iron, the main metal contaminant in ancient copper. For trace elements found in smelted copper, see Pernicka 1999: 163-186 and Tylecote, Ghaznavi and Boydell 1977: 305-333. For a summary of the experimental archaeology studies into LBA refining practices, see Merkel 1983a: 173-178.
[896] Atzeni 2005: 21.

The LBA refining process melted the black copper in a crucible commonly positioned in clay lined pit with foot bellows as shown in Figure 6.35.[897] The refining process is shown in the schematic below.




**Schematic 6.3: LBA refining process**

Charcoal was used as the fuel and air was pumped through tuyères from foot bellows, forming the reductive environment required to oxidise the contaminants. Silica granules $SiO_2$, when added as a flux to the metal melt at above 600 °C, removed most of the iron in the form of iron oxide and non-metal contaminants, forming an iron-rich siliceous slag $FeO.SiO_2$, which could be easily skimmed off the surface.[898]

$$SiO_2 + 2FeO \rightarrow 2FeO.SiO_2$$

During this process some of the melted copper oxidised into copper oxide (CuO), which rapidly converted into cuprous oxide $Cu_2O$, as shown below.[899]

$$2Cu + O_2 \rightarrow 2CuO$$
$$2CuO + CO \rightarrow Cu_2O + CO_2$$

To maximise the copper output and remove any copper sulphide, the melt was stirred with green branches through a covering of charcoal, which immediately started to burn. The resulting hydrocarbons formed in conjunction with the reductive atmosphere enabled the cuprous oxide to combine with any remaining copper

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897 Tylecote 1980b: 196-199.

898 Bachmann 1982: 21.
In this stage, the volatiles, mainly sulphur inclusions and arsenic oxide together with some of the trace metals, were driven off as fumes. Manganese, cobalt, and tin that were also in solution in the molten copper combined with the flux and were removed with the slag (Atzeni 2005: 21). Traces of these metals remain in the refined metal, and these, combined with those in the slag. form a valuable diagnostic indicator for archaeo-metallurgists of the processes used in antiquity. See Bachmann 1982a: 143-151 for the application of analytical data to Cypriot metallurgy.

899 Only the main chemical reactions are given. Many complex reactions depending on the exact contaminants present were taking place in parallel and are outside the scope of his thesis.

sulphides $CuS_2$ to release sulphur dioxide $SO_2$ into the atmosphere. In this chemical reaction the cuprous oxide $C_2O$ is reduced to pure copper.[900] The chemical reaction being:

$$2CuO + CuS_2 \rightarrow 6\ Cu + SO_2.$$

Although our understanding of the refining process is largely derived from experimental archaeology, the success achieved in decontaminating the smelted copper by ancient metallurgists is clear from archaeological records. Craddock's chemical analysis of 346 Timna copper objects showed that only three had iron contents greater than 7.5% and over half had less than 0.5% iron content[901]. Similarly, Maddin's analysis of 19 samples from the Ulu Burun wreck ingots, seven samples from Gelidonya ingots, 17 samples from Crete and 11 samples from Cyprus all show that low iron contents of around 0.5% had been achieved.[902]

Merkel's experimental archaeology showed that a minimum of three refining cycles were required to reach these low levels of iron and sulphur. With three cycles, he decreased the iron content of the black copper from 22.2% to 6.2%, and sulphur from 0.49% to 0.18%. Re-melting a second and third time reduced the iron content to 3 and 2% respectively.[903] Merkel's results show that to get to the 0.5% threshold level achieved by the ancient metallurgists at least five refining cycles were required, and this factor has been used in the quantitative manpower study below.

Details of the time taken for melting and refining and the quantity of silica flux required to refine black copper have not been published. Merkel observed in his refining experiments that copper melted very quickly but did not record the time taken.[904] Some assumptions can, however, be deduced from his published data

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[900] Atzeni 2005: 21, Kelso 1951: 26-28.
[901] Craddock 1980: 165, Craddock 1988: 178 particularly Figure 1, and for a histogram of the iron content of all the copper bronze artefacts, see Craddock 1995: 138-139, particularly Figure 4.7.
[902] Maddin 1989: 100-101. Two exceptions were from two of the Ulu Burun ingots, which had iron concentrations of 1.22% and 2.14%. This shows the problem of quality control facing ancient smelters. For a wider Near East-Europe wide analysis of the iron content of bronzes, see Craddock 1999: 181-184, particularly Table 1.
[903] Merkel 1983a: 177, table 1. Table 1 gives the full analysis of all constituents for the first refining experiment. Merkel states that he eventually achieved an iron content of 0.014%, but does not say how many further cycles were required. The drop in iron content in each cycle suggests that at least a further two cycles, five in total, were required to reach an iron content of 0.5%.
[904] Merkel 1990: 116-118.

relating to smelting of Timna ore nodules, and this will be used for the input variables in the quantitative refining analysis.[905]

The major limiting factor for any pyro-metallurgical process in antiquity was the flow of air that could be sustained continuously over a long period. Merkel's smelting and refining experiments showed that a team of four or five operators, working three at a time (taking turns on the foot bellows), could supply three tuyères each with a continuous air supply of 350 litres/min.[906] A crucible in a lined pit would have a smaller thermal capacitance than the Timna shaft furnaces on which Merkel based his experiments.[907] An estimate of the relative volume of Merkel's shaft furnace shows that the mass to be pre-heated was 11 times greater than that of the Piramesses crucible furnace.[908] Merkel's furnace took up to three hours to be pre-heated, so, assuming pre-heating time is directly proportional to the mass of the furnace, which is in turn proportional to volume, then the Piramesses furnace would have taken 0.32 hr to be pre-heated.[909] The total estimated elapse time to pre-heat the Piramesses furnace plus three refining cycles would therefore have been 2.46 hr.[910] The resulting man-years to refine the equivalent weight of black copper ingots found on the Ulu Burun wreck would be up to 10 and 12 man-years respectively for Piramesses and Cyprus.[911]

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[905] See report 6.5.1-6.5.5 in BRONZECALC. A summary of 16 smelting experiments are given in Merkel 1990: 86-87, Table 1-2.

[906] Experiments 26-29 in Table 2 (Merkel 1990: 86).

[907] The thermal capacitance is the ability of a material to absorb and store heat. It is calculated by the product of the mass of the body measured by its specific heat. Thermal capacitance, conductivity, and resistance are analogous to electrical properties and can be used in calculations in a similar manner.

[908] This estimate is based on the drawings for Merkel's furnace and the excavated Piramesses furnace. See Report 6.5.3 in BRONZECALC for the full analysis.

[909] This is a simplification of the heat flow through furnace materials, as it ignores losses beyond the furnace. However, it is close enough to be used for this application. For input assumptions as to the length of time to pre-heat the furnaces based on charcoal burning rates and charcoal consumed pre-heating the furnace, see Merkel 1990: 86-87, Table 1-2. These assumptions have been used in Report 6.5.3 in BRONZECALC.

[910] See Reports 6.5.5 in BRONZECALC. I am grateful to Neil Burridge, tutor for the 'Bronze Age Flat Axe Course' held at the Weald and Downland Museum in Singleton, Hampshire, UK for personal communication and a helpful discussion on crucible pyrotechnology. The author recognises that the assumptions made are based only on limited empirical evidence, and a fully-controlled work process study of the LBA refining process based on the Piramesses cruicible furnace (see again Figure 6.35) would make a valuable future research project.

[911] Report 6.5.2 in BRONZECALC.

## Alloying copper and tin to make bronze

This section will discuss the processes and manpower required to alloy copper and tin to make bronze. It will not quantify the manpower required to cast bronze into artefacts, which for the purposes of this thesis is part of the discretionary use of surplus by the elite for the production of added-value goods, as discussed in the next chapter. Tin can be added to copper in either a solid form or a molten state. A high tin content makes bronze easier to cast, producing castings with less defects, and a number of factors may have influenced the proportion of tin added to copper to produce bronze. The relative scarcity of tin, and therefore its cost, would obviously have been a factor, but this had to be balanced against the need for more charcoal to cast low-content bronzes. The optimum relationship between these two factors, as discussed earlier in Section 6.1, shows that the most common mix in the Bronze Age was 90% copper and 10% tin by weight, and this mix will be used in the quantitative study.

The process of alloying was less complex than smelting or refining and would have been completed in one cycle. The weight of copper on the Ulu Burun wreck, allowing a loss of 10% for corrosion, was 10,478 kg the estimated weight of tin was 1,000 kg.[912] This is almost equal to the optimum 10 to 1 copper to tin ratio required to make tin. Assuming the same furnace pre-heat time and melt time as refining, the manpower requirement to alloy the combined weight of the copper and tin ingots on the Ulu Burun wreck would be 4 man-years for both Cyprus and Piramesses. The next section will show that charcoal was a precious resource and its cost could not be ignored. For example Bronze made with 25% tin required less charcoal for casting, as it has a melting point of 798 °C, compared with 6% tin, which melts at 1036 °C. [913]

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[912] For weight distribution and corrosion of copper ingots on the Ulu Burun, see Pulak 1997: 235-239, Pulak 2000c: 140-144, figures 7, 8 and Lin 2003: 206, Table 7.1. For the estimate of the weight of the tin ingots on the Ulu Burun, see Pulak 2000c: 152.

[913] Rowlands 1976: 9.

# 6.3 Charcoal production processes in the LBA

This section will discuss the large quantity of charcoal and wood required to support the LBA bronze production.[914] Charcoal, made from hard woods, was used for the smelting, refining, and alloying of copper and tin, and is produced when wood is heated with insufficient air for combustion in a temperature in excess of 480°C.

Charcoal has three main benefits over wood for pyro-metallurgical processes. Charcoal can achieve higher temperatures in furnaces.[915] It produces a reductive environment when burnt with a limited air supply, producing the carbon monoxide essential for smelting, refining and alloying operations.[916] A higher heat output is achieved with charcoal, as it has higher carbon content than wood per unit weight.[917] As a consequence more precise temperature control can be achieved, because smaller quantities of charcoal than wood can be added at a time for the same energy input.[918]

The traditional process of making charcoal, either by an earth-covered mound or a pit, has not changed essentially from the Bronze Age to today (Figures 6.36-6.37). Making charcoal is a labour-intensive process and involves cutting down trees, trimming the felled trees, transporting wood to the charcoal maker, stacking the wood, covering with earth to limit combustion, and finally breaking the charcoal into pieces suitable for use in furnaces.[919] A measure of the time and cost taken to produce charcoal is demonstrated by annual accounts of the Radmer Kupferbergwen

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[914] As noted wood was also used for firesetting in central Asian tin mines and for roasting Cypriot copper sulphide ores.

[915] Charcoal burns naturally at 900°C but, with forced air, temperatures of 1600 °C can be attained within the furnace (Sim and Ridge 2002:21).

[916] Wood tends to produce carbon dioxide when burnt within a furnace, rather than the carbon monoxide required to produce a reductive atmosphere.

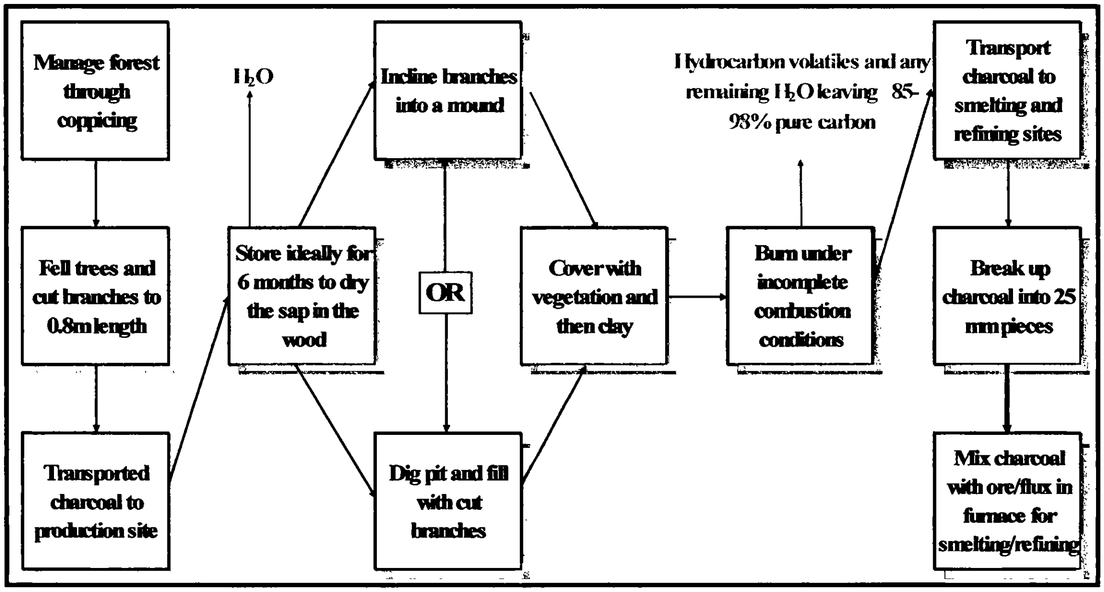
[917] The calorific value of charcoal is 7,400 kcal/kg, compared with 3,580 kcal/kg for green wood (FAO 1985). Depending on the type of wood used to make it, charcoal has a carbon content ranging from 78-92%, compared to 50% content in wood. This increases the thermal efficiency of the furnace because the 'net energy gain' in the furnace increases. The 'net energy gain' applied to the case of a furnace is defined as the energy of fuel minus the sum of all the losses, the main losses being any residual heat energy in the exhaust fumes, plus any thermodynamic losses, such as conduction, radiation or convection. For a schematic of all the heat sources and losses in an ancient furnace used for smelting or refining, see Bamberger and Wincierz 1990: 146, Figure 18.

[918] Charles 1994: 66, Craddock 1995: 192, and Horne 1982a: 9-10.

[919] If the charcoal pieces are too small, the forced draught blows the light charcoal out of the furnace. If too large, the flow of gases is impeded, creating cold spots in the furnace. Merkel 1990: 81 showed that pieces of around 25 mm diameter were the optimum size. At Timna site pieces of acacia charcoal were found up to a diameter of 35 mm.

for 1608 and 1610 A.D. These accounts show that 75% of the cost of production of copper was spent on making charcoal.[920]

The processes involved in making charcoal are illustrated in the schematic below.




**Schematic 6.4: Charcoal production process**

The quantitative analysis in module 8 of BRONZECALC follows the charcoal process outlined above and calculates the manpower that would have been required to make sufficient charcoal to produce bronze from the weight of the copper and tin ingots found on the Ulu Burun wreck. Ethno-archaeological, modern and historic evidence and experimental replication of charcoal production processes are included. The environmental impact of charcoal production will be discussed, and the sheer scale of production and cost will be shown.

In Ancient Egypt and the Wadi Arabah close to Timna, charcoal was made from a range of tree woods: acacia, juniper, oak, olive, pistachio and the tamarisk trees.[921] In

[920] Marshall 2003: 11-12, Tables 1a-1b. Similarly, the accounts of the powered iron bloomery at Tudeley in Kent for the period 1329-1334 A.D. show that the cost of charcoal amounted to 50% of the total cost of producing 6000 lbs of iron per annum This is a useful comparator to LBA copper smelting operations, as the bloomery also operated with foot bellows (Tylecote 1962: 273 citing Guiseppi 1912: 145-164).

[921] Charcoal found at Timna was made from Acacia sp, *Acasia gerrardii var. negevensis, Pistacia atlantica.* Acasia sp, *Acasia gerrardii var. negevensis, Pistacia atlantica* grows in the area mainly in *wadi* beds (Werker 1988: 232, Table 1 and Rothenberg 1962: 17-19). For a wider view of Arabah, see Scheel 1989: 27 and Engel and Frey 1996: 29-39. Engels in particular has shown from his archaeo-botanical analysis of ancient slag heaps in the Arabah that by the end of the LBA/EIA the tamarisk tree was the main source of wood for charcoal production (Engel 1993: 205-211). As it has a lower calorific value than the other hard woods, this indicates that charcoal makers were forced to use the

Cyprus charcoal was made from mixed forests of dwarf oak (*Quercus alnifolia*), hawthorn, olive, and pine (*Pinus brutia*) on the lower slopes of the Troodos Mountains, and from the coastal oak (*Quercus lusitanica*) and poplar.[922] Hard wood was preferred to soft wood for making charcoal, as it has a higher carbon content and thus produces higher temperatures in furnaces. The key requirement of charcoal is it should not crumble in transport or produce too much charcoal dust in the furnace, which would be blown out of the furnace through the action of the bellows.[923]

## 6.3.1 Demand for charcoal

The discussion starts with an assessment of the weight of charcoal required to smelt, refine, and alloy into bronze the copper and tin ingots found on the Ulu Burun wreck (10,478 and 1,000 kg respectively). This will demonstrate the scale of the charcoal industry required to support bronze production and the environmental impact on the ancient forests. On Cyprus the ores were pre-roasted and wood used as the fuel source for this, which added to total demand for wood there.[924]

### Charcoal required for smelting copper and tin

Merkel's experimental archaeology for smelting showed that, on average, a shaft furnace based on those from site 2 and 30 from Timna and operated with foot bellows required up to 51 kg of charcoal to produce one kg of copper.[925] The experiments of Tylecote *et al* showed that 40 kg of charcoal was required to produce 1 kg of copper.[926] This lower number is due to the fact that Tylecote did not pre-heat the furnace with charcoal, but instead used gas burners.[927] Timberlake's experiments in the field using a simple crucible furnace resulted in an average charcoal

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scrubby tamarisk tree, suggesting that there was either a climate change at the time, or that other species had been deforested. Tamarisk trees, despite being difficult to cut and giving a low heat output when burnt, did have the advantage over hardwood trees of rapid growth (Newton 2005: 363).

[922] Knapp 1999b: 237 and Raber 1987: 303.

[923] Tylecote 1986: 225.

[924] This will be discussed in more detail below.

[925] Merkel 1990: 107. Craddock 1995: 194 described a useful measure for the fuel required to make one kg when examining ancient sites where the slag remains are intact. His rule of thumb is that for every one kg of slag produced, 2 kg of charcoal were required.

[926] Tylecote 1977: 306.

[927] Tylecote 1977: 307. Merkel's experiments using bellow operated reconstructed furnace in the field required on average 16.4 kg of charcoal to pre-heat the furnace (Merkel 1990: 87, Table 2).

consumption rate of 70 kg of charcoal per kg of smelted tin.[928] These empirical statistics show that the charcoal requirement for smelting the ingots on the Ulu Burun wreck would be 534,378 kg of charcoal for the copper ingots and 70,000 kg of charcoal for the tin ingots.[929]

## Wood required for roasting Cypriot sulphide ore

In addition to the wood required for charcoal production, wood was required in Cyprus for the roasting of sulphide ores (discussed in Section 6.2.2 above) and for pit props.[930] Allan's analysis of Roman copper mining at Rio Tinto indicates that for every kilogram of copper ore that was smelted and refined, an average 21.8 kg of wood was used to roast the ores.[931] The wood requirement for roasting the ore required to make the Ulu Burun wreck copper ingots would therefore be 228,420 kg.[932]

## Charcoal required for refining copper

It has been assumed that the refining of Timna black copper and alloying with tin was carried out at Piramesses.[933] For Cyprus refining is assumed to have taken place at one of the coastal centres of Enkomi, Kition, and Hala Sultan Tekke.[934] The

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[928] Timberlake 1994: 121-234. This charcoal combustion rate seems high on face value compared with Merkel's experiments, but crucible smelting is less thermally efficient due to a smaller cubic capacity than the designs of the larger shaft furnaces used at Timna. Rehder 1999: 312-313, Figure 3 has demonstrated how furnace size influences the heat input required to maintain temperature. This is due to the fact that the external surface area of the furnace (through which heat is lost) which encloses the furnace fire, compared with the volume of the fire itself, shows a lower ratio for a bigger furnace than for a smaller furnace.

[929] The full analysis is given in Reports 6.7.1 and 6.7.2 in BRONZECALC.

[930] Pit props have survived in archaeological records in the mining galleries of Skouriotissa, Mitsero *Kokkinoyia*, and Apliki (Knapp 1999b: 237). The abundance of props in archaeological records suggests that the demand for wood for this purpose was significant, particularly as props were rarely reused, as once jammed into position they could not be removed. The annual demand for pit props is difficult to quantify, so it has been ignored for this analysis. The demand for wood should therefore be treated as a minimum requirement for Cyprus.

[931] Allan 1970: 10.

[932] This equates to a volume of 331.0 $m^3$, assuming the wood was dwarf oak (*Quercus alnifolia*) with an average density of 690 $kg/m^3$ (see Table 1 in Wolffia 2007). The full analysis is given in Reports 6.7.3 in BRONZECALC.

[933] This assumption is supported by the excavation reports of the industrial-scale Piramesses metal working site near modern Quantir (Pusch 1989a: 76-113 and Pusch 1989b: 145-170).

[934] Enkomi is a large site (15 ha) on the north-east coast, with extensive ashlar masonry buildings built to a grid pattern (Negbi 1986: 101-105). Copper and bronze artefacts and debris (1.1 tons) have been found at the site (Knapp 1986: 80-84 and Pickles and Peltenberg 1998: 90-92). Kition, with its harbour in Larnaca Bay on the south-east coast, was another large metal-working centre (Karageorghis and Kassianidou 1999: 171-188). In Kition a number of crucibles and incomplete

analysis of the manpower required for refining the copper ingots on the Ulu Burun wreck in Reports 6.5.2 in BRONZECALC shows that the total number of refining cycles required in Cyprus or Piramesses would have been 374 and 524 respectively. Merkel's refining experiment 27D showed that the charging rate of charcoal in the furnace required an average of 10 kg/hr.[935] The total time taken to refine the copper ingots on the Ulu Burun wreck if made in Cyprus and Piramesses would have been 4,413 and 4,333 hrs respectively, and multiplying these times by the charcoal charging rates gives a total charcoal requirement for refining this quantity of copper if carried out in Cyprus or Piramesses would have been 44,132 and 43,335 kg respectively.[936]

**Total charcoal requirement to alloy the copper and tin ingots found on the Ulu Burun wreck**

A similar analysis to that above in Reports 6.7.5 in BRONZECALC shows that Cyprus and Piramesses would require 16,400 and 14,130 kg of charcoal respectively to alloy into bronze the copper and tin ingots found on the Ulu Burun wreck.[937]

## Summary of the demand for charcoal and its implications

The case study to determine charcoal requirements for the end-to-end process of producing bronze from the copper and tin ingots found on the Ulu Burun wreck dramatically demonstrates the size of the charcoal industry in the LBA. The total charcoal required to make bronze from the Uluburun copper and tin ingots is shown in the table below.

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furnaces have been excavated, which is particularly interesting as they are so rare in archaeological records (Tylecote 1982: 91). Recycling of copper and bronze seems to be linked to temples in Cyprus and the Levant (Artzy 1999: 27-31, Karageorghis and Kassianidou 1999: 172-173 and Knapp 1986; 43-56). Hala Sultan Tekke, a coastal settlement 4 km east of Kition, has archaeological evidence of industrial-scale metal-working complete with both metallurgical recycling and refining of debris and workshops (Åström 1982: 177-181, Bachmann 1976: 127-128, and Tylecote 1982: 87).

[935] Merkel 1983a: 177-178, Merkel 1983b: Table 31, and Merkel 1990:

[936] The full analysis is given in Reports 6.7.4 in BRONZECALC.

[937] It has been assumed that the charcoal requirements for alloying a mass of copper and tin equal to the mass of copper refined would be the same charcoal per unit weight of metal. I am grateful for a discussion on this matter through personal communication in 2006 with Neil Burridge, traditional smelter and bronze caster at the Weald and Downland Museum, Singleton, Hants, UK. He estimated that energy requirements would be similar for both operations.
http://www.wealddown.co.uk/Courses/courses-early-technology.htm#bronze%20flat%20axe.

| Process | Cyprus | Egypt |
|---|---|---|
| Smelting copper | 534,378 | 534,378 |
| Refining copper | 44,132 | 43,335 |
| Smelting tin | 70,000 | 70,000 |
| Alloying copper and tin | 16,400 | 14,130 |
| **Total charcoal requirement kg** | **664,910** | **661,843** |

**Table 6.4: Total charcoal requirements for the end-to-end process of producing bronze from the copper and tin ingots on the Ulu Burun wreck**

The charcoal required to make one kg of bronze for Cyprus and Egypt is 58 and 57.7 kg respectively. As stated above Cyprus required an additional 21.8 kg of indigenous oak to roast sufficient sulphide ore to make one kg of copper if using.

**Deforestation**

One of the problems for the copper industry in the Bronze Age, and later the iron industry, was deforestation. This problem was exacerbated by the need for charcoal for casting metals, annealing and work-hardening metal objects, religious offerings, and faience and glass production.

Deciduous mixed forests of mainly oak and pine that have been cut down take between 50-80 years to grow again. Constantinou has calculated that 200,000 tons of copper have been produced in Cyprus over the last 3,000-4,000 years.[938] To support this copper production with charcoal, the entire area of ancient forests of Cyprus would have been replaced 16 times over this period.[939] One strategy that may have been used to minimise deforestation is the coppicing of the hardwood trees that grow on the island.[940] Many of the gaps formed when hardwood trees were felled may also have regenerated quickly through colonisation by fast-growing red pines (*Pinus brutia*).[941]

The analysis in Report 6.7.8 in BRONZECALC shows the weight and volume of wood and the number of trees required to make sufficient charcoal to smelt, refine

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[938] Constantinou's analysis is based on his study of ancient slag remains (Constantinou 1982: 23).
[939] The area of ancient forest has been estimated to be 15,000,000 ha (Constantinou 1982: 22, citing data provided by the Forestry Department of Cyprus).
[940] Burnet 2004: 35 and Wertime 1982: 356. Wertime states that the dwarf oak (*Quercus alnifolia*) can be coppiced from the roots and harvested at a rate of 1-1.5 metric tons/acre.
[941] Burnet 2004: 86. Pit props and charcoal remains in slag heaps show that *Pinus brutia* were used in the copper industry (Burnet 2004: 35, Knapp 1999b: 237, and Given, Knapp and Coleman 2003: 72, 172-177, Figures 4.56-4.57).

and alloy the copper and tin ingots found on the Ulu Burun wreck, and these results are shown in the table below.[942]

| Wood requirements for the Ulu Burun study | Cyprus | Timna |
|---|---|---|
| Weight of wood required for roasting ore, firesetting, and charcoal needed for the Ulu Burun case study | 4,018,407 | 4,632,900 |
| Vol. of wood required m³ | 6378 | 6177 |
| Number of trees required assuming only one third of the tree suitable for charcoal | 105,748 | 154,430 |

**Table 6.5: Weight and volume of wood and the number of trees required to smelt, refine and alloy the copper and tin ingots found on the Ulu Burun wreck**

While the ancient forests of Cyprus could perhaps have sustained with some difficulty this level of tree felling, the area around Timna certainly could not have without causing deforestation. Bachmann has suggested that the mines of the south Negev, exploited in the EBA, LBA, and the Roman period, ceased production due to deforestation rather than lack of demand.[943] One contributory factor for the migration from bronze to iron at the end of the LBA/EIA may be that the estimated weight of charcoal required to make 1 kg of bronze was 58 kg, whereas iron only required 7-11 kg of charcoal for every kg of iron produced.[944]

## 6.3.2 Traditional production methods for making charcoal

This section analyses the manpower required for the felling of trees and preparing of wood for the charcoal maker, the production of charcoal in pits or heaps, and the transport of the charcoal to the smelting sites. For reasons of convenience, transport costs for charcoal are analysed in this section rather than with the other transport costs analysed later in Section 6.4.

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[942] The assumptions and their respective references are given in Reports 6.7.8-6.7.10. One important assumption is that it is unlikely that the main trunk of hardwood trees or even thick branches above 0.1m were used in antiquity for charcoal production. Cleere 1976: 240 suggests that only branches from the tree were used for charcoal production, and this amounts to 33% of the weight of a hardwood tree. To split trunks and thick branches to make them suitable for the charcoal kilns used in antiquity would not have been cost-effective using the tools available in antiquity. Instead these larger pieces of wood became a valuable resource for shipbuilding. It is interesting to note that Strabo, in his *Geography* 14.6. 4-6, 383, quotes Eratosthenes as saying that the two main exports from Cyprus were copper and timber.

[943] Bachmann 1980: 215-236.

[944] Experimental results by Crew, Cleere, and Tylecote all showed ratios of between 7-16 kg of charcoal to 1 kg of iron bloom (Crew 1991: 26, Figure 2, Crew 1991: 21, citing Cleere 1970. *Iron Smelting Experiments in a Reconstructed Roman Furnace*, London, The Iron and Steel Institute, and Tylecote, Austin and Wraith 1987: 345-353, Figure 32, Table 13).

Egyptian wall paintings do not show how charcoal was made in the LBA, so evidence for the production process must be based on ethnographic, classical, and historical evidence. Classical texts show that the process of charcoal making was well understood.[945] As LBA pyrotechnology was similar to that used in the classical period, it is probable that the method used to make charcoal was the same. The consensus of archaeo-metallurgists is that the process has essentially remained the same up to the present day and is still used in less developed modern cultures. The oldest and probably most widely-used method for charcoal production was the earth clamp kiln. These came in two basic designs, the pit and the mound, and the latter was particularly suitable for rocky areas. Both designs are shown in the engravings in *Pirotechnia* by Biringuccio in 1540 A.D. (see again Figures 6.36-6.37).[946] The illustration of the heap kiln is remarkably similar to one described in Theophrastus *Historia plantarum* 5.9 4:

> For charcoal burning they select smooth logs to be stacked densely in a pile; when they coat the pile with clay they ignite it and pierce holes in the coating.

Horne's ethnographic study of charcoal making in the rural, arid Iranian plateau illustrate that bell-shaped pits have remained in use up to the present day. These bell-shaped pits were dug and lined with stone to keep out the surrounding earth and filled with wood before lighting a fire in the centre. The entry of air is restricted by the small opening in the top of the bell-shaped pit, and this is sealed when the fire is established. All the volatiles of the wood are driven off in the restricted hot air environment to produce pure carbon.[947]

In Egypt it is known that an extensive charcoal industry flourished in both the Sinai and the Eastern Desert.[948] Rothenberg suggests that the source of charcoal was acacia trees and brushwood found in the nearby saline marshes near Yotvatah and along the Wadi Arabah (Figure 6.38). Rothenberg's estimate is that a medium-sized acacia tree

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[945] Theophrastus, *Enquiry into Plants* 5.9.1-4, 6, Theophrastus, *Concerning Fire* 28-29, 37 and Pliny, *Natural History* 16.23, 34, 8, 96.
[946] Pleiner 2000: 115-130.
[947] Horne 1982a: 10-11 and Horne 1982b: 202-215.
[948] Gale *et al* 2000: 353, citing Petrie, W.M.F. and C.T. Currelly (1906). '*Researches in Sinai*'. London: John Murrey. 52.

would produce 30 kg of charcoal.[949] The branches of a 0.25 m diameter pine tree, more typical of Cyprus, could produce 38 kg of charcoal.[950]

## Experimental replication of charcoal production in antiquity

This section examines the traditional charcoal-making process and assesses the method used in antiquity, so that the manpower requirements for making charcoal can be determined. Traditional methods of producing charcoal reduce the volume of timber by 25% and its weight by 75%. This means that 1 kg of charcoal can be made from 1.65 kg of wood with a 15% water content, and 2.5 kg of green wood with 60% water content. To improve the efficiency of the charcoal-making process, the cut wood cab be left to dry, avoiding wasting energy that would otherwise be used for evaporating the wood sap.[951]

Two experimental archaeological studies carried out by Pleiner replicated the process described in Biringuccio's *Pirotechnia*. The first experiment used logs cut to 0.6 m, laid in horizontal layers in a mound 2.5 m in diameter at the bottom and 2 m at the top, and 1.4m high. The wood was covered with green branches and moist turf and mud to prevent ingress of air through the sides. The mound produced 70 kg of charcoal from 400 kg of chopped wood (a 17.5%, or 1 to 5.7, yield). The process took 48 hrs and needed constant monitoring to ensure that the clay covering did not crack, allowing an ingress of air.[952] The second experiment was on a larger scale, producing 100 kg of charcoal from 570 kg of pine (also a 17.5% yield), but this time taking a longer period of 68 hrs. Biringuccio's illustrations indicate that two men were needed to build and monitor the firing. Pleiner's study used logs, which were more representative of the trees found in Cyprus than the scrubby character of the

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[949] Rothenberg 1978: 9.
[950] Baskerville 1965: 867.
[951] Meiggs 1982:4.
[952] It is this problem of combustion in an oxygen rich atmosphere due to ingress of air that is still a problem for charcoal makers today using traditional methods. To account for this in antiquity the number of cycles for the Ulu Burun wreck case study has been increased by 15
%. I am grateful for this information from a personal communication with Paul Pinnington, traditional charcoal maker at the Weald and Downland Museum, Singleton, Hants, UK. http://www.wealddown.co.uk.

acacia trees found in the Arabah.[953] For this reason in BRONZECALC, the charcoal requirements for Timna will assume a wood to charcoal ratio of 1 to 7.[954]

## 6.3.3 Manpower requirements for producing charcoal

The experimental and historical data used as input assumptions and the analysis to assess the manpower requirements for producing charcoal are provided in Reports 6.7.8-6.7.12 in BRONZECALC. The analysis is in three parts: Report 6.7.9 determines the manpower required for lumbering, Report 6.7.10 estimates the manpower required to build and operate the charcoal clamp and pit kilns, and Report 6.7.11 estimates the transport costs associated with moving the fuel to the smelting and refining centres.

### Manpower requirements for cutting timber

Report 6.7.8c in BRONZECALC calculates the number of trees required to make sufficient charcoal to smelt, refine and alloy the copper and tin ingots found on the Ulu Burun wreck.[955] Shirley's manpower studies of the Roman Army estimate that it took one man with an axe and two men pulling on ropes 1.5 hours to fell an average-sized pine. This equates to 4.5 man-hours, to which 2 man-hours must be added for trimming the tree branches into pieces suitable for a charcoal clamp or pit kiln using sickles, giving a total of 6.5 man-hours/tree.[956] Multiplying this unit felling time with the number of trees required to be felled within the Ulu Burun wreck study gives a manpower requirement for Cyprus and Timna of 279 and 408 man-years respectively.

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[953] Pleiner's study gave ratios of 1:5.7 charcoal to wood by weight. Cleere 1976: 240 study of the fuel requirements for Roman iron working in the Kentish Weald suggests that in antiquity 1:7 was a more realistic ratio using scrub wood.
[954] To test the sensitivity of these assumptions see Report 6.7.8c in BRONZECALC. This test has analysed the four combinations of wood to charcoal ratio on the total manpower required to support the end to end process to make bronze from the 1,000 kg of tin and the 10,480 kg of copper found on the Ulu Burun wreck. The maximum and minimum range for these eight combinations is 4.6% and 3.4% for Cyprus and Timna respectively.
[955] This assumes that the weight of wood that could be made from an average Cypriot pine was 38 kg.
[956] Shirley 2001: 41-42, Figure 18 and Cleere and Crossley 1985: 133-135. In his field charcoal production experiments, Pleiner used branches cut to a length of 0.6 m (Pleiner 2000: 126).

## Manpower to build and operate the charcoal clamp and pit kilns

To build an earth-covered clamp or pit kiln would have taken two men approximately a day (two man-days in total).[957] Pleiner's charcoal-making experiments gave unit production rates of 0.680 hrs/kg of charcoal.[958] As stated previously throughout the charcoal production stage, the kilns have to be continuously monitored to prevent any ingress of air which would cause the wood to ignite rather than carbonise.[959] As the wood in Cyprus was more suitable for charcoal production in terms of branch size, the lower rate will be used for Cyprus and the higher rate for Timna. The resulting manpower to produce sufficient charcoal to smelt, refine and alloy the copper and tin ingots on the Ulu Burun wreck for Cyprus and Timna/Piramesses would be 504 man-years and 502 man-years respectively.[960]

## Manpower requirements for the transport of wood and charcoal

Cleere states that for charcoal carried over a distance greater than 6 km by pack animals, a significant proportion of its weight would have been broken up into charcoal fragments and dust.[961] This means that the distances charcoal can be transported and still be of use in furnaces is limited. Deforestation in Cyprus or even the normal low density of trees in the Arabah raises the possibility that the ancients may well have had to transport the wood to charcoal production centres rather than charcoal to the smelting or refining centres. As charcoal is 75% lighter than wood and wood is more difficult to carry than charcoal, the cost of transport becomes greater the farther away available the wood supplies.[962]

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[957] I am again grateful for this information from personal communication with Paul Pinnington, traditional charcoal maker at the Weald and Downland Museum, Singleton, Hants, UK. http://www.wealddown.co.uk.
[958] See Reports 6.7.10a-6.7.10b.
[959] Pleiner 2000: 126.
[960] See Report 6.7.10a in BRONZECALC.
[961] Cleere and Crossley 1985: 103.
[962] For all transport analyses hereafter, it is assumed that all transport was by donkeys, and that a pack animal could carry 75 kg weight for sustained periods of time (Horne 1982b: 205). Two donkey handlers were required to control ten donkeys, and the donkey train could move at an average speed of 4 km/h. For maintaining donkeys in prime condition as pack animals, see ethnographic evidence from Ram *et al* 2004: 407-412. The daily water requirement for a donkey in hot environments ranges from 18-35 litres/day (Aganga and Letso 2000).
For a LBA assessment based on textual evidence of the metal trade of Ugarit and the problems of transport of commercial goods, see Heltzer 1977: 203-211.

The most likely site for wood to make charcoal for Timna was the salt marshes of Yotvatah, 17 km away (see again Figure 6.38). There were trees growing near Timna in the Wadi Arabah 8.5 km away, but they were of limited use as the trees grew sparsely.[963] The main source for wood, therefore, was from the salt marshes. Donkey handler requirements for transporting fuel to the smelting sites of Cyprus and Timna are 25 and 30 man-years respectively.[964] For reasons given related to direction of the flow of charcoal and wood, these transport manpower requirements must be considered a minimum.

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[963] For tree density levels in desert areas with minimal rainfall, see Andersen and Knut Krzywinski 2007.
[964] For the full analysis, see Report 6.7.11 in BRONZECALC.

# 6.4 Transport considerations

The purpose of this section is to estimate the costs associated with the transport involved in supporting the LBA bronze industry in Cyprus and Egypt. Figures 6.39-6.40 shows that there were many possible routes for the flow of copper, tin and bronze to and from Cyprus and Egypt.[965] It has been assumed for reasons of energy, transport, and logistics that the smelting operation was carried out close to the mines, and that refining copper, alloying with tin and casting of bronze was carried out close to towns and ports.[966] To illustrate the cost of transport, only a few of the many combinations will be considered, and to assist comparison between Cypriot and Egyptian transport costs, the tin and bronze ingots found on the Ulu Burun wreck will be used as examples. The evidence will be discussed in two parts, first the transport costs associated with Cyprus, and then those of Egypt.[967]

In order to assess transport costs for Cyprus and Egypt, eight routes have been analysed (see again Figure 6.39). For Cyprus, these are: the transport of tin from central Asia to Ugarit (route 1), the transport of tin from Ugarit to Cyprus by sea (routes 2 or 3), the transport of black copper from the Cypriot Apliki mines to the refining centres on the coast of Cyprus (route 4), and the transport of black copper or bronze from Enkomi to Ugarit (route 5). In the case of Egypt, four routes have been analysed: the transport of tin from central Asia to Piramesses (routes 1 and 6), and the transport of copper from Timna to Piramesses, either by land or part of the journey by sea (routes 7 and 8). The evidence for the trading routes and transport methods used for the movement of smelted tin and copper will be provided for each case.[968]

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[965] A useful article on the many alternative trading routes that connected the Eastern Mediterranean is given in Astour's article "Overland Trade Routes in Ancient Western Asia" (Astour 1995: 1401-1420). For textual sources of the trade routes for tin, see Heltzer 1977: 207, Muhly 1973: 290-326, Larsen 1976: 86-105, and Yener 1980: 23-43. For an extensive review of the possible LBA sea routes linking the Aegean to the Eastern Mediterranean ports see Wachsmann 1998: 295-299.
[966] Knapp 1990b: 160 and Stech 1985: 102-103.
[967] The transport costs incurred in making charcoal have been analysed separately in the section above.
[968] The length of routes discussed below should be considered the minimum. Routes require many detours, particularly when across rocky terrain. As pack animals were used for transport detours when crossing dry territory, available water sources would be a necessity, as a donkey requires between 25-38 litres of water per day depending on work rate and ambient temperature (Aganga and Letso 2000).

Textual evidence shows that donkeys were the primary beast of burden in the Eastern Mediterranean.[969] They are hardy, sure-footed animals capable of carrying 50-75 kg over medium distances and up to 100 kg for short journeys.[970] Provided they had adequate rest breaks for watering and feeding, they could travel up to 20-24 km/day, depending on the terrain.[971]

## 6.4.1 Land and sea transport costs associated with Cyprus

### Route 1: Cost of transporting tin from Uzbekistan to Ugarit

The main caravan routes used in the LBA across Asia to the Eastern Mediterranean are examined, so that the costs of transporting tin overland from central Asia can be estimated. The main trading routes used in the Bronze Age are shown in Figure 6.41. The exact route taken by the tin traders in the LBA is not known, so this thesis has assumed that the shortest distance was used, from Uzbekistan to Ugarit's port of Mahadu, with an estimated distance of ca. 2,300 km (Figures 6.41-6.44).[972] A caravan carrying the equivalent load of tin to that of the Ulu Burun wreck (1,000 kg) would take 15 donkeys 103 days to reach Ugarit.[973] As tin was such a valuable commodity, it would be surprising if armed guards were not also part of the caravan team, as the use of soldiers to guard valuable trading and mining expeditions is well known in antiquity. It has been assumed that 25 armed guards would be needed to provide adequate security for the caravan train.[974] The cost of the donkey handlers

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[969] While donkeys dominated pack transport, there is evidence from Egyptian tomb paintings that mules had been introduced by the Eighteenth Dynasty. Tuthmosis had also used ox-carts to move boats overland for the crossing of the Euphrates, and Ramesses II also used ox-drawn carts for the Kadesh campaign (Faulkner 1953: 46-47 with full references). For an interesting treatise on the role of the donkey in Egyptian everyday life, see Janssen 2005.
[970] Mumford 2006: 48, fn 38 and Heltzer 1977: 203-211.
[971] Alexandra the Great moved on average 20 km/day over long distances with a rest day every 7 days. Over shorter distances with a rest day every seven days this increased to 22.5 km/day. Ancient Assyrian and Medieval Chinese texts show that their armies achieved 24 km/day (Murnane 1990: 95-96). This analysis will assume 22.5 km/hr for the average speed of 24 km/day which allows time for feeding and watering of pack animals.
[972] From EBA and MBA textual evidence the LBA route probably passed through the same ancient cities of Nineveh, south of Carchemish, Emar, Alleppo, through the mountain pass to the east of Ugarit at Magdala, to Ugarit's capital at Ras Shamra. Deduced from Astour 1995: 1401-1420, Heltzer 1977: 207, Margueron 1975: 201-213, and Muhly 1973: 290-36. This ancient route trade route would have varied over time due to any current political unrest.
[973] For the full analysis see Report 6.6.1 in BRONZECALC.
[974] In some periods trade routes in Mesopotamia had to be diverted, owing to the action of hostile natives. See discussion of tin and lapis lazuli imports into Mesopotamia using the ancient Khorāsin road through the Northern Zagros (Muhly 1973: 317).

and security guards would equate to a manpower cost for transport and security of 11 man-years.

## Routes 2 and 3: Cost of shipping tin from Ugarit to Cyprus

Cyprus, being an island, depended on its tin imports being delivered by sea. Archaeological records clearly show that Enkomi, Kition, and Hala Sultan Tekke were large-scale copper refining and bronze production centres (see again Figures 6.14).[975] As Ugarit was the closest port, this analysis assumes that tin deliveries were shipped from Ugarit to Enkomi.[976] This could have been accomplished by sailing direct to Enkomi (route 2 ca. 175 km) or by 'tramping' in an anticlockwise direction along the coast of Anatolia, around Cyprus to Enkomi (route 3 ca. 950 km).[977] The route chosen by the boat owners would probably have been decided on the basis of economic considerations, which favoured mixed loads which could be exchanged at more than one point. For this analysis, the cost of sea transport compared to land transport has used a ratio of 28:1, which was developed by Duncan-Jones by comparing transport costs land versus sea based on the evidence from Diocletian's Edict.[978] The Roman ratios would probably be applicable to the LBA, as the marine transport technology of LBA boats was comparable to those of the Romans.[979] However, Report 6.6.4 in BRONZECALC shows that using these Roman ratios and the distances by sea of the two possible routes, Enkomi from Ugarit direct (ca. 175 km), and a coast-hugging route around Anatolia (ca. 950 km), the sea transport costs

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Textual evidence shows that Egypt soldiers invariably accompanied convoys of valuable goods or people. A letter (papyrus pCairo ESP, Document C in the reign of Ramesses IX) describes how the Medjai (Nubian elite troops) protected supplies to the gold mines, and the same text lists 25 knives and 25 axes that supplemented the bows of the protection force. It is reasonable to assume then that there was a minimum of 25 troops protecting the supplies, as the value of the tin and copper considered in this thesis would have been sufficient to require similar levels of troops. Transliteration and German translation by Hafemann 2007.

[975] See earlier footnote 138.

[976] Kition or Hala Sultan Tekke could equally have been chosen.

[977] For justification of tramping in the LBA using evidence of the distribution of LBA Aegean pottery, see Cherry and Davis 1982: 333-341. Tramping is a term introduced by Braudel to refer to circular trading voyages along the coast with frequent stops en-route to trade. Usually taking several weeks or months, the result of this succession of selling, buying, and exchanging of goods was that the cargo often changed completely in nature from the cargo at the start of the voyage (Braudel and Ollard 1992: 107). For an analysis of Cypriot harbours with some distance between them, see Knapp 1997b: 158.

[978] Duncan-Jones 1974: 366-9.

[979] See Fitzgerald 1996: 8-9, Pulak 1999: 209-238 and Pulak 2000a: 28-34 for similarities between the mortise and tenon hull construction used in the construction of LBA ships to that of the classical period.

are so small as to be meaningless.[980] It has therefore been assumed for the purposes of this study that the coast-hugging route 3 was chosen, with a nominal cost allocation of one man-year.

Route 4: Cost of transporting Cypriot black copper overland from the Troodos mines to the coastal ports along the west and south-west coasts of Cyprus

In Cyprus, the copper smelted at Apliki or similar mines on the northern edge of the Troodos Mountains was most probably exported from the coastal ports of Enkomi, Kition, or Hala Sultan Tekke. The journey by donkey would probably have followed the river valleys down from the mountains and would have been approximately 110 km in length (see again Figure 6.14).[981] Using the same assumptions as those for overland transport, the manpower requirement would have been two man-years.[982]

## 6.4.2 Egyptian transport costs linked to the bronze industry

### Routes 1-6: Overland costs of transporting tin

#### Route Uzbekistan to Egypt via Ugarit

Egypt's demand for tin would have incurred even higher costs, as the tin had to be carried on from Ugarit to Piramesses. Despite alternative methods of transport by sea with lower attendant costs (discussed below), Egypt and Anatolia seemed to prefer land to sea transport.[983] Piramesses has been chosen as Egypt's most likely destination, as the ongoing archaeological excavations at this Ramesses II site are uncovering evidence of industrial-scale metallurgical facilities (Figure 6.45).[984] Transporting tin to Piramesses from Ugarit would have added approximately 900 km

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[980] These equate to routes 2 and 3 shown in Figure 6.39.

[981] Cypriot rivers are not navigable, but the river mouths do provide anchorage points for small boats, as Bronze Age anchors have been found at Maroni on the south coast. In winter (November to March) the rivers become torrents and the river valleys become for the most part impassable. During the rest of the year, many rivers dry up and they can be easily used by loaded donkeys for the transport of smelted black copper down from the mines to the coast (Knapp 1997a: 154 and Hatcher 2007: 9).

[982] For the full analysis, see Report 6.6.5 in BRONZECALC.

[983] Despite the use of a port at Ura on the Southern coast of Anatolia it is known from texts that an overland caravan route connected Hittite Asia Minor with Ugarit and Egypt (Heltzer 1977: 207 with full textual references). For cost comparisons of sea transport and land transport see section above on transporting tin by sea from Ugarit to Cyprus (routes 2-3).

[984] This site is close to modern Quantir in the Delta. Excavations have been undertaken since 1984 under the direction of Edgar B. Pusch, as part of a joint Austrian-German mission on behalf of the Pelizaeus-Museum in Hildesheim. For an overview of the metal working facilities at Piramesses see Pusch 1989a: 76-113 and Rehren, Pusch and Herold 1998: 233.

to the journey, and the manpower effort including security required for the whole journey from Uzbekistan to Piramesses via Ugarit, carrying the equivalent of the 1,000 kg of tin found on the Ulu Burun wreck, would have been 5 man-years.[985]

## Routes 7 and 8: Transporting Timna black copper to Piramesses

Two routes were possible for the transport of tin from Timna to the large copper refining and bronze production centre at Piramesses on the Nile Delta. No LBA record survives on the actual route moving the smelted copper to Egypt. Mumford suggests that the route taken in the Late Old Kingdom from Memphis to the quarries and copper/turquoise mines on the West coast of the Gulf of Suez was by land to Ayn Sukhna and then by boat across the Red Sea to Ras Budran (Figure 6.46).[986] It is possible that in the Ramesside period boats were used to transport copper down the Gulf of Eilat and following the Sinai Peninsular coast to Ras Budran before crossing the Red Sea to Ayn Sukhna (route 8). The distance travelled in route 8 would be 155 km overland and 425 km by sea. As the evidence seems to indicate that Egyptian sea expeditions by sea were the exception rather than the rule, route 7 across the Negev and down the coast to Piramesses would probably have been the preferred route.[987] This would have passed through the Negev desert to the coast and then down the coast to Piramesses (route 7 ca. 500 km), requiring 4 man-years for donkey handlers and security (Figure 6.47).[988]

## Transport costs moving workers to the mining centres

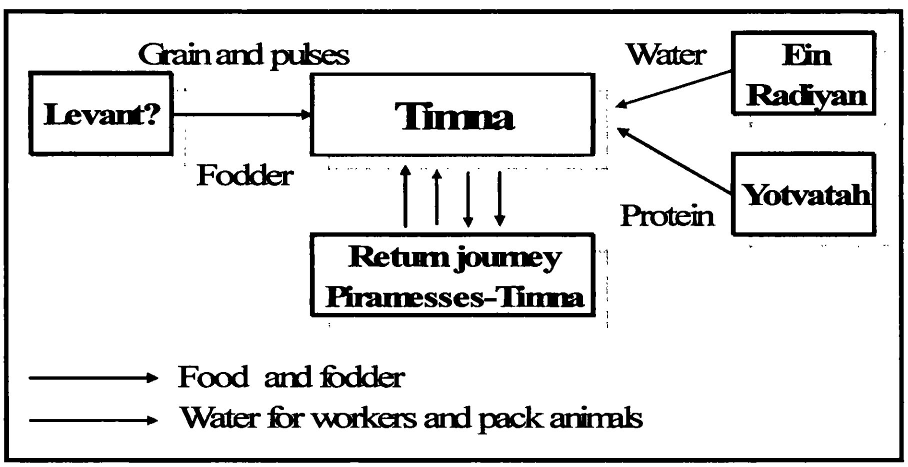
Owing to the high ambient temperatures in Timna, mining and smelting was probably seasonal and would have required a return journey each year.[989] This must

[985] The full analysis is given in Report 6.6.2 in BRONZECALC.
[986] Mumford 2006: 14, Figure1.
[987] Not all scholars accept Egypt was a sea going nation. Fabre 2005: 12-13 provides a concise summary of the main arguments for and against. The capability of providing sea transport is demonstrated in Sahure's burial temple at Abusir illustrating a return voyage along Syro-Levatine coast (Wachsmann 1998: 12, Figure 2.3). One of the most famous Egyptian sea-going journeys was Hatshepsut's expedition to Punt illustrated in her mortuary temple at Deir el Bahri (Wachsmann 1998: 18-24, Figures 2.15-2.18, 2.25-2.28)
[988] For the full analysis, see Reports 6.6.6-6.6.7.
[989] Petrie and Currelly 1906: 96ff and Rothenberg 1962: 42. It has been assumed for the case of Cyprus that the close proximity of the mines to the agricultural villages on the lower slopes of the north side of the Troodos Mountains and to the agricultural plain (5-15 km) means that the travel time was insignificant and can be ignored. Mining in Cyprus may also have been seasonal to ensure sufficient labour was available for gathering in the harvest.

be considered an overhead, because the workers had to be fed but during the journey they were unproductive. Assuming that the overland route was taken (route 7), the return journey would have taken up to 45 days, which must be considered a major cost for the Timna operation. Each season this migration of metal workers from Piramesses equates to a cost of 1131 man-years.[990]

## Transport costs associated with transport of supplies

The final demand for manpower resources was the supply of food and, in the case of Timna, water for the mine workers and smelters. Reports 6.8.1-6.8.4 provides a full analysis and includes the assumptions used. Timna has been chosen to highlight the significant logistical effort required to provide food and water for the mineworkers and their pack animals, as shown in the schematic below. Mines in the Troodos Mountains had lower logistical costs, as water was available from mountain streams and food supplies from agricultural districts bordering the mountains.[991]




**Schematic 6.5: Transport of food, fodder, and water to Timna**

The analysis of ancient diets discussed in Section 3.2.2 in Chapter 3 showed that an adult male required 260 kg/year of grain and 110 kg/year of pulses in their diet. Protein in the form of wildfowl was probably sourced from the salt marshes at Yotvatah. For this exercise it is assumed that the grain was procured from markets bordering the Levant (100 km return journey), and transported by donkey caravans to Timna. This operation would have required 94 man-years of donkey handlers'

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[990] See Report 6.8.2 in BRONZECALC.
[991] Knapp 1997a: 58.

effort.[992] While travelling to and from Piramesses and Timna each season, workers would require feeding from supplies carried by donkeys, and this operation would require 117 man-years of effort by the donkey handlers.[993]. In addition, water was in short supply in the arid conditions of Timna. Humans require 3.5 litres per day in hot conditions if they are undergoing rigorous exercise, while donkeys require 27 litres per day.[994] The nearest water supply is at Ein Radiyan, a round trip of ca. 30 km from Timna. Assuming that half of the donkeys' water requirement had been satisfied before leaving Ein Radiyan, it would have been necessary for them to carry water for their own needs for the overnight stop at Timna. Report 6.8.4 in BRONZECALC shows that the manpower effort for donkey handlers required supplying both workers and donkeys with water for a six-month season would have been 156 man-years. A summary of the total manpower costs incurred in supplying food and water, and in transporting workers to and from to the mining centres each year, is given in the table below.

| Route taken | Donkey handlers | |
|---|---|---|
| | Cyprus | Egypt |
| Tin Uzbekistan to Ugarit (route 1) | 11 | 11 |
| Tin Ugarit to Piramesses (route 6) | - | 5 |
| Copper mines to refining centres (routes 4 and 7) | 2 | 4 |
| Supply of food to the metal workers each season | 33 | 94 |
| Transport miners food transit in/out of Timna (route 7) | - | 117 |
| Transport wood and charcoal | 28 | 31 |
| Transport drinking water for donkeys | - | 25 |
| Transport drinking water for human consumption | - | 131 |
| **Total donkey handlers man-years** | **74** | **418** |

**Table 6.6: Manpower required to support donkey transport**

The final consideration is the cost of fodder for the pack animals. When based at Timna, it is likely that fodder was sourced locally or from the Levant, rather than transporting alfalfa or barley from Egypt. Either way it was a significant cost and should be considered in the total cost equation. The accumulative number of years that the pack animals work per season is given in the table below. For reasons of

[992] Egypt maintained hegemony over the Levant in the LBA. Having assumed above that the Egyptian workers would have travelled to and from Piramesses each season overland via the Levant, supply sources would probably have been well established. For analysis see Report 6.8.3 in BRONZECALC.
[993] Transport requirements for fodder will be considered below.
[994] See Aganga and Letso 2000.

convenience, these years are defined as donkey-years for the calculation of fodder and the manpower required growing this fodder.[995]

| | | |
|---|---|---|
| Total donkey-years required for the Ulu Burun case study | 174 | 1619 |
| Man-days to grow and harvest alfalfa for one donkey/year | 2 | 5 |
| Total man-days to grow and harvest alfalfa for one donkey/year | 348 | 8095 |
| **Total man-years to grow and harvest fodder for one donkey/year** | **2** | **27** |

**Table 6.7: Total man-years to grow and harvest fodder for one donkey/year each mining season**

## 6.4.3 Summary of transport costs

Adding together all the elements of transport costs for the Ulu Burun wreck study, including the manpower to grow fodder, produces transport costs of 109 and 1,576 man-years for Cyprus and Timna/Piramesses respectively, which clearly shows why Cyprus was a lower-cost producer of copper than Egypt. All the elements of costs are summarised below.

| **Preferred routes taken in the LBA** | **Transport costs man-years** | |
|---|---|---|
| | **Cyprus** | **Egypt** |
| Tin Uzbekistan to Ugarit (route 1) | 11 | 11 |
| Tin Ugarit to Piramesses (route 6) | - | 5 |
| Copper mines to refining centres (routes 4 and 7) | 2 | 4 |
| Supply of food to the metal workers each season | 33 | 94 |
| Transport miners food transit in/out of Timna (route 7) | - | 117 |
| Transport wood and charcoal | 28 | 31 |
| Transport drinking water for donkeys | - | 25 |
| Transport drinking water for human consumption | - | 131 |
| **Total donkey handlers man-years** | **74** | **418** |
| Time lost travelling each season | 33 | 1131 |
| Total cost of producing or buying fodder | 2 | 27 |
| **Total transport cost man-years** | **109** | **1,576** |

**Table 6.8: Summary of the man-years associated with transport costs incurred in producing the quantity of copper and tin found on the Ulu Burun wreck**

995 In Report 3.17f in AGCALC analyses the man-years needed to cultivate fodder. The range varied depending on the available of natural pasture for fodder. The estimated manpower to grow fodder for Cyprus and Egypt was estimated to be between 2 and 5 man-days per donkey per year respectively. It is assumed that 15 and 35% of the fodder had to be grown using a crop such as alfalfa for Cyprus and Egypt respectively.

# 6.5 Chapter summary and discussion

## 6.5.1 Consolidated manpower requirements

This quantitative study shows that the manpower required to produce one kg of bronze is 0.454 man-years/kg of bronze and 0.815 man-years/ kg of bronze for Cyprus and the Egyptian-controlled mine at Timna respectively. The manpower to produce the 1,000 kg of tin and 10,480 kg of copper on the Ulu Burun wreck and then alloy them together would be up to 5,207 man-years and 9,355 man-years for Cyprus and Egypt respectively. Overall this shows Egyptian bronze with copper mined at Timna and alloyed with tin from Uzbekistan and alloyed at Piramesses was 180 % more expensive than Cyprus as a bronze producer, in terms of manpower. The table below is a manpower summary of all the processes involved in making bronze.

| SUMMARY CYPRUS | IMPORTED TIN | COPPER | BRONZE | TOTAL |
|---|---|---|---|---|
| Extraction of ore | 281 | 153 | - | 434 |
| Firesetting in Uzbekistan | 33 | - | - | 33 |
| Beneficiation | 203 | 3334 | - | 3,537 |
| Roasting of sulphide ore | - | 21 | - | 21 |
| Smelting ores | 28 | 222 | - | 250 |
| Refining | - | 10 | - | 10 |
| Alloying | - | - | 4 | 4 |
| Charcoal production | 85 | 703 | 20 | 808 |
| Transport and fodder costs | 17 | 92 | 1 | 110 |
| TOTAL MAN-YEARS | 647 | 4,535 | 25 | 5,207 |
| SUMMARY TIMNA | IMPORTED TIN | COPPER | BRONZE | TOTAL |
| Extraction of ore | 281 | 2,722 | - | 3,003 |
| Firesetting in Uzbekistan | 33 | - | - | 33 |
| Beneficiation | 203 | 3334 | - | 3,537 |
| Roasting of sulphide ore | - | - | - | 0 |
| Smelting ores | 28 | 222 | - | 250 |
| Refining | - | 12 | - | 12 |
| Alloying | - | - | 4 | 4 |
| Charcoal production | 100 | 819 | 20 | 939 |
| Transport and fodder costs | 19 | 1,557 | 1 | 1,577 |
| TOTAL MAN-YEARS | 664 | 8,666 | 25 | 9,355 |

**Table 6.9: Total man-years to produce copper and tin ingots and alloy them together to make bronze, broken down into the major production processes**

The analysis for Timna is in reality an underestimate, as the analysis has assumed that the equivalent of the copper and tin ingots was smelted in one year. The scale of manpower required, and more importantly the problems of supplying food and water in Timna, make the spreading of production over a number of years more likely.

It is also interesting to note how beneficiation and charcoal production dominated production costs, as shown in the table below. Again they clearly show the impact of transport to Timna on its overall costs.

| Percentage | Cyprus | Timna |
|---|---|---|
| Extraction of ore | 8.3 | 32.1 |
| Firesetting in Uzbekistan | 0.6 | 0.4 |
| Beneficiation | 67.9 | 37.8 |
| Roasting of sulphide ore | 0.4 | - |
| Smelting ores | 4.8 | 2.7 |
| Refining | 0.2 | 0.1 |
| Alloying | 0.1 | 0 |
| Charcoal production | 15.5 | 10 |
| Transport and fodder costs | 2.1 | 16.9 |
| **TOTAL** | **100** | **100** |

**Table 6.10: Percentage breakdown of costs for Cyprus and Timna/Piramesses**

Notwithstanding the uncertainties of many of the assumptions used in this analysis, the scale of manpower resources expended on the production of the Ulu Burun wreck raises a number of interesting points. It may explain why Alašiya (Cyprus) was courted by other powers in the LBA to procure copper through gift exchange.[996] It may also explain why exploitation of copper deposits in the Arabah, particularly Timna, has fluctuated so much from the Bronze Age through to the present day.[997] This may point to an Egyptian strategy to only produce copper from the Arabah deposits when foreign policy created peak demands for bronze, because of military campaigns. It may not be a coincidence that peak production at Timna coincided with the Reign of Ramesses II, who led many military campaigns during his long reign.[998]

[996] The Amarna letters between the King of Cyprus and the King of Egypt will be discussed in the next section.
[997] I am grateful to Dr. G. Mumford (currently lecturer at University of Alabama (Birmingham, USA) for permission to include in this thesis his analysis of Egyptian artefacts found in southern Sinai (Figure 6.46). They clearly demonstrate how irregular Egyptian occupancy was throughout Pharaonic history.
[998] This assumes that the battle was in his regnal year five, and he came to the throne in 1304 B.C. Some scholars have proposed he came to the throne in 1279-8 B.C., and this depends on how the Sothic date given in the Papyrus Ebers is interpreted (Grimal 1992: 250-252).

# Chapter 7: The nature of the LBA economy

## 7.1 Introduction

The aim of this thesis was to answer the question "How does the proportion of manpower resources dedicated to non-basic activities inform us about the nature of the LBA economy?" For the purposes of this study the 'nature' of the LBA economy is defined as having three core characteristics: the scale of the LBA economy in terms of Gross Domestic Product and interregional trade, the economic and political interaction between the ruling élites of the Eastern Mediterranean, and the degree to which the economy was embedded in the institutions of the state.[999] Non-basic manpower refers to the manpower dedicated to satisfying state needs and conspicuous consumption needs as defined in the Schematic 7.1 below.

In Chapters 3-6 the principle LBA agrarian and manufacturing processes have been identified using a '*chaînes opératoire*' methodology that breaks down a process into its constituent activities.[1000] From these process elements, the workforce (man-days) required to complete the tasks have been evaluated using as evidence a wide range of published archaeological, textual, tomb paintings, ethnographic, and experimental archaeology.[1001] Only when the harvest had successfully met the basic needs of the society (food, clothing, and shelter) could the state needs be met, and both had to be fulfilled before the conspicuous consumption needs of the élite could be realised (see

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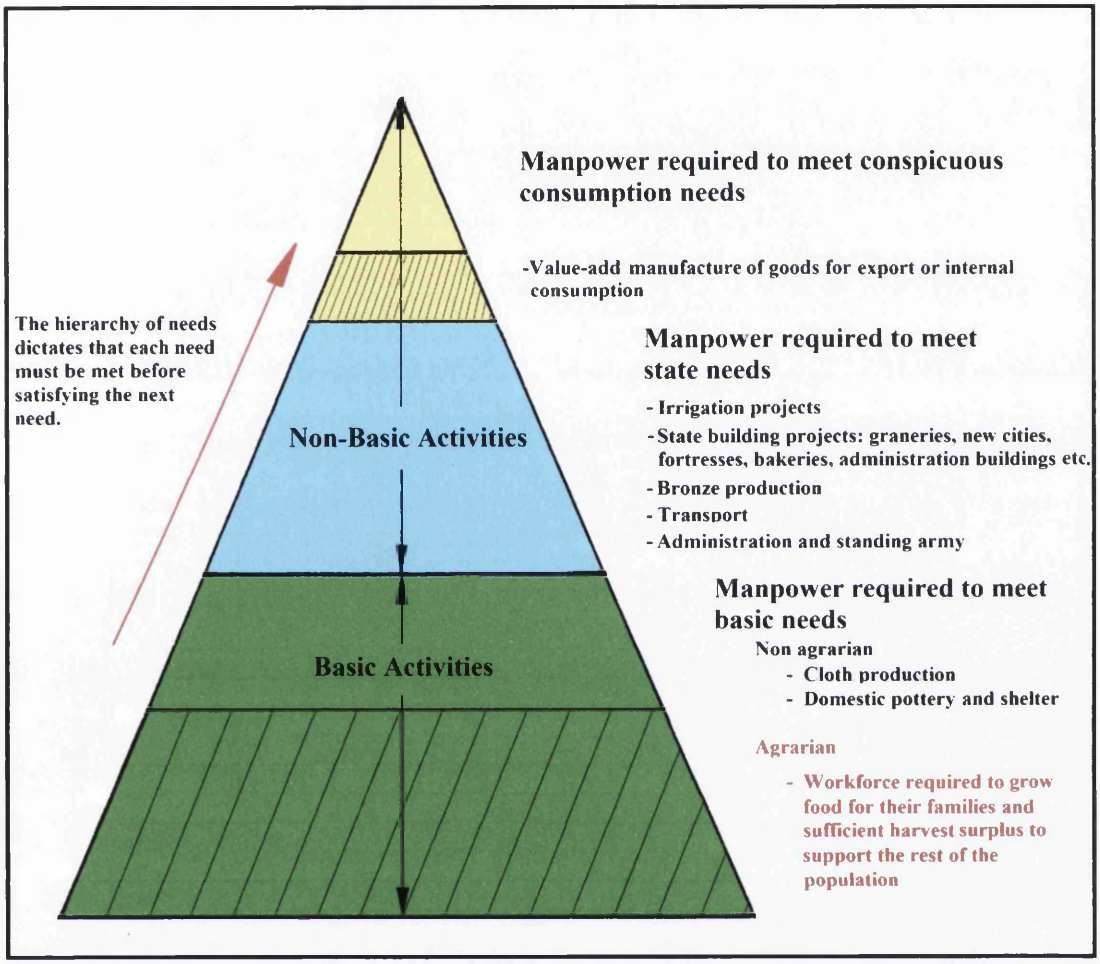
[999] Douglas C. North defines institutions as: "the humanly devised constraints that structure political, economic and social interaction. They consist of both informal constraints (sanctions, taboos, customs, traditions, and codes of conduct), and formal rules (constitutions, laws, property rights). Throughout history, institutions have been devised by human beings to create order and reduce uncertainty in exchange" (North 1991: 97).
Gross Domestic Product (hereafter GDP) is a measure of the size of the economy in a particular region. It is defined as the total value of all goods and services produced within that region during a specified period (most commonly, per year). The neo-classical definition of GDP = consumption + gross investment + gross spend + (exports-imports). Discussion of trade, unless otherwise stated, refers to interregional exchange not exchange transactions in local markets. Hopkins was the first to innovatively apply the concept of using GDP to estimate the taxation levels for financing the Augustan Roman army (Hopkins 1980: 101-125, Hopkins 2002: 190-230).

[1000] This is a methodology used in manufacturing and service industries that examine the methods of carrying out activities of processes in order to improve their productivity, improve service levels to the customers of the process, and provide objective, measurable standards of performance for the activities carried out. In the UK and USA *chaînes opératoire* is better known as work study in industry. *Chaînes opératoire* is used in this thesis as it has become the *de facto* term in academic publications for analysing the activities within ancient processes.

[1001] For convenience to avoid very large numbers, man-days have been converted to man-years assuming that a worker due to sickness, festivals etc worked 308 days/ year (discussed previously in Section 3.4).

again the hierarchy of needs schematic above). It is the analysis of the management of the manpower requirements to satisfy this hierarchy of needs that provides one of the contributions of this thesis to the debate on the scale, operation and nature of the LBA economy.[1002]




**Schematic 7. 1 showing the manpower requirements to satisfy the hierarchy of needs as applied to LBA cultures.1003**

Some of the highest priorities for the use of manpower would have been to support state infrastructure projects such state granaries for redistribution control, a standing army, sea going ships, administration centres, and the manufacture of bronze tools and weapons, and for Egypt, the management of the inundation. The list is limitless and choices would have been made on the investment manpower that was essential for the effective operation of the state before any consideration could be given to

[1002] The concept of a hierarchy of needs was first used by the behavioural philologist Abraham Maslow who hypothesized that human endeavour could be explained in terms of striving to fulfil a hierarchy of needs that individuals attempt to meet; the accomplishment of one need allows release for the individual to fulfil another at a higher level (Maslow 1970).

[1003] This schematic is conceptual and makes no attempt to represent arithmetic proportions.

meet the conspicuous consumption needs of the élite. The manpower required to satisfy the conspicuous consumption needs of the élite is the final element of the hierarchy of needs. A part of this chapter will be a consideration of the level of added-value manufacture of goods produced by the state (shaded yellow in Schematic 7.1 above).[1004] How much was dedicated to added-value activities compared to state infrastructure projects would be at the discretion of the élite. An indicator of how 'embedded' the LBA economy was within the institutions of the culture would affect the choices made by the élite as to how this workforce was allocated. The ruling élites working within a substantive (embedded) economy would tend to have a high proportion of the non-basic workforce dedicated to investments in state buildings, standing armies, and temples. The ruling élite accrued conspicuous consumption goods through gift reciprocity between ruling élites. In a formalist economy the 'market' is outside the control of the ruling élites, though their actions contributed to fluctuations of supply and demand.[1005] In such an economy the non-basic workforce would therefore tend to be directed towards producing those added-value goods and services that responded to the needs of the market. The ruling élites therefore would be reacting to market forces through a rational decision making process. A substantive economy would be less responsive to market forces, more introspective, with a greater emphasis on satisfying the needs of the institutions of the state.

This chapter will be concentrating on the last 200 years of the LBA, 1400-1200 B.C., which was the period when the ruling élites were faced with rapid changes in the world around them. An unprecedented level of contact was taking place between ruling élites which required improved communication and diplomatic processes.[1006] The archaeological and textual record shows that LBA merchants had mutually understood communication processes that allowed agreement on value and exchange to take place. Developments in metal alloying technology resulted in an increasing dependence on tin from distant Central Asia. Bronze therefore became the alloy of choice for weapons and tools and created an unparalleled demand for copper and tin.

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[1004] For earlier definition of 'added-value' see Section 1.1, page 1.

[1005] Substantivism (embedded) and formalism (market driven following the laws of supply and demand) were discussed in Chapter 2.

[1006] We know from the Amarna Letters that communication between ruling élites in Akkadian was possible and commonplace.

Marine technology had improved both ship design and carrying capacity. Supporting maritime activities were harbours around the Mediterranean providing shelter and services for long distance trading missions. This resulted in new markets opening up in those regions which before the LBA had been impossible to reach on a regular basis. Improved shipping technology also led to an increase in the scale of goods moving around the Mediterranean. All the elements necessary for a formalist economy were in place for the LBA regions to become more reactive to market forces, but working against this was a history of conservative traditionalism where the institutions were deeply embedded in the cultural values of the state. How the ruling élites came to terms with these two conflicting influences is the core of this discussion on the substantive or formalist nature of the LBA economy.

This discussion will start with an overview of the unresolved debate as to whether the ancient economy should be interpreted from a modern economic (formalist) perspective or from an anthropological (substantive) perspective. The overview will identify the main areas of divergence between the two views and these divergences provide the criteria that this chapter will evaluate from the evidence developed in Chapters 3-6. In addition other relevant archaeological, textual, and ethnographic evidence will be discussed and conclusions drawn about the nature of the LBA economy.

# 7.2 The scale of the LBA economy

The overall objective of this section is to determine whether the scale of the LBA economy for the period 1400-1175 B.C. was or was not 'minimalist' in scale. The first stage will be to consolidate the 'cost analyses' from Chapters 3-6 to determine the proportion of the workforce that was dedicated to non-basic activities as defined in Schematic 7.1 above. This consolidated data will be used to identify the proportions of the total workforce available to satisfy the basic, state, added-value production, and conspicuous consumption needs of a region, which together can be considered as their Gross Domestic Products of their economies.[1007] It is the size of the non-basic workforce available which can be fed, clothed, and sheltered that will indicate whether the scale of the economy for the period 1400-1200 B.C. was minimalist or not. Bücher, Weber, and Finley viewed the added-value sector of the ancient economy as minimalist in scale with the majority of the population working on the land. They believed that the agrarian majority only provided a small surplus that could support a few craftsmen producing goods directly or via gift exchange, to satisfy the conspicuous consumption demands of the ruling élite. Showing that the added-value sector was not minimalist in scale does not in itself point to a formalist economy. It is possible to have a large scale substantive economy based on administered trade. A thriving added-value sector is an attribute of a formalist economy but one of the most important attributes of formalism is whether an economy responded to market demands or whether the economy was embedded. This chapter will use the evidence from Chapters 3-6 to determine how large was the non-basic workforce, how much of this was dedicated to added-value production, and whether there is sufficient evidence from the textual sources to conclude that there was a direct relationship between price and fluctuations in supply and demand.

All cultures in antiquity were fundamentally agrarian in character and based on redistribution of locally grown grain and pulses.[1008] In antiquity the supply of food was constrained by the primitive level of farming technology and the geographic position of the region which dictated the level of water available for crops. Two

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[1007] Basic, state, and conspicuous consumption needs as defined above in Schmatic 7.1.

[1008] Some Egyptian scholars differ on the extent of redistribution in New Kingdom Egypt particularly Warburton 2007: 175-194, Cooney 2007b and Cooney 2007c: 8-16. For a thorough review of the textual evidence for the Mesopotamian redistribution see Gelb 1965: 230-243.

regions and their economies have been chosen for detailed study, Cyprus because of its extensive copper resources, and Egypt because it was the largest economy in terms of GDP in the LBA generated from its large harvests produced in the fertile Nile Valley. Cyprus with a rain fed dry farming industry was subject to droughts. Egypt's agriculture was totally dependent on the height of the annual inundation which was at the mercy of the rainfall in Sudan and Ethiopia.[1009] Comparing and contrasting Cyprus with Egypt will highlight the possible strategies open to them when faced with harvest failures or the opportunities for interregional trading contact in times of average harvests or glut.

It is the numbers of non-basic workers that can be supported from this harvest surplus over and above those too old or young to work that provide a convenient measure of potential for economic growth through added-value activities. This measure will be used to determine if the non-basic sector of the LBA economy was minimalist or not. The manpower data from Chapters 3-6 is consolidated next into the categories of the hierarchy of manpower identified above in Schematic 7.1. This will quantify the proportion of workers involved in non-basic activities, mainly dedicated to added-value production.

## The workforce required to satisfy basic and non-basic needs

At the base of the hierarchy of needs that had to be satisfied were the physiological requirements for water and food. For this study it has been assumed that all East Mediterranean regions had found an earlier solution to the provision of water for drinking purposes using an infrastructure of wells, cisterns or easily attainable water from rivers.[1010] The production of food required a large workforce to produce sufficient calories to maintain a physical healthy lifestyle. AGCALC shows that to maintain a population of 100,000 people of all ages and gender in a healthy state requires 86,065 million kcals/100,000 people.[1011] By convention demographic population studies use a cohort of 100,000 sample population to be representative of

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[1009] By convention rain fed regions in the Mediterranean and Near East have been commonly referred to as dry farming regions. Regions such as Egypt and Mesopotamia reliant on rivers for irrigating crops are called hydraulic cultures, a term first used by Butzer (Butzer 1976).

[1010] Some effort would be required for maintenance of wells and cisterns and the collection of daily water requirements but this would be small compared with other needs and has been ignored.

[1011] See Reports 3.2-3.9 in AGCALC and Section 3.2 relating to the LBA diet in Chapter 3.

the whole population. Chapter 3 has shown that to feed a cohort of 100,000 men, women and children in Egypt required up to 37,205 agrarian workers. For rain dependant agriculture regions such as Anatolia, Aegean, Cyprus, and the Levant, this increases to 47,490 agrarian workers/100,000 population, mainly due to the lower yields of staples.[1012] Another basic need requiring a dedicated workforce was the production of cloth. For Egypt using flax, and Cyprus using wool, this would require workforces of 14,659/100,000 population and 10,430/100,000 population respectively.[1013] It was shown in Chapter 5 that the basic needs of domestic shelter did not require significant manpower resources. Although the population of Egypt has been estimated to have increased over the New Kingdom by 0.95 million, this only represents a growth rate of 829 per annum at the end of the new Kingdom (480 years).[1014] The need to build new houses therefore was minimal and could be satisfied with a workforce of 920 men/100,000 population.[1015] Brick production for state projects however was a major investment and its associated manpower requirements will be discussed in state investment (particularly state granaries) in Section 7.2.1. Similarly, the manpower required to make traditional hand thrown pots in simple kilns fired by dung was also minimal.[1016]

A summary of the workforce to meet the basic needs of Egypt and Cyprus are shown in the table below.

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[1012] The average yield taken for barley, emmer wheat, and pulses in Egypt were 1057, 1156, and 1582 kg/ha respectively. The average yield taken for the more rocky dry farming regions such as Mainland Greece, Crete, and Cyprus for barley, emmer wheat, and pulses was 660, 714, and 563 kg/ha respectively. For the full analysis for both cases see Reports 3.10-3.13 in AGCALC and Section 3.4 in Chapter 2. Within this analysis it has been assumed that the weight ratio of seed corn to yield was 1 to 10 and wastage was 15%. These parameters were incorporated the AGCALC calculations that determined the number of agrarian workers above. This is discussed fully in Section 3.5.2 and the analysis given in Reports 3.15c, 3.16c, 3.20a and 3.21a.

[1013] The analysis in Chapter 4 is based on workload that has been converted into equivalent full time male and female workers (previously discussed in Section 3.4). Ethnographic evidence shows that females dominated spinning and weaving operations, fitting in the work between family responsibilities. Working at irregular intervals is not as efficient as full time production so the man-days required is higher than the workload.

[1014] See Report 5.2 in SHELTER.

[1015] Covered in Chapter 5, Section 5.2.1 and Reports 5.5a-5.5c.

[1016] Based on ethnographic evidence of an Indian potter, Report 3.44 in AGCALC shows that 66 potters would meet the demand for domestic pots for a 100,000 sample population/annum.

| Allocation of manpower/ 100,000 population | Egypt | Cyprus |
|---|---|---|
| Housing to satisfy population growth | 920 | 920 |
| Domestic pottery | 66 | 66 |
| Agriculture | 37,205 | 47,490 |
| Clothing | 14,659 | 10,430 |
| **Total workforce supporting basic needs** | **52,850** | **58,906** |

**Table 7.1: Total workforce/100,000 population required to meet the basic needs of Egypt and Cyprus**

Demographic studies of populations in antiquity suggest that in a population sample of 100,000, 22,460 would have been aged six or less and 8,400 would have been over 55 years.[1017] It is reasonable to assume that these age cohorts would not have contributed to any meaningful manual work but they still had to be fed.[1018] It can be seen in the table below that in the LBA out of every 100,000 population there would have been 13,320 male and female workers available for non-basic work for Egypt and 7,264 male and female workers in Cyprus.[1019]

| Allocation of manpower/ 100,000 population | Egypt | Cyprus |
|---|---|---|
| Total workforce supporting basic needs | 52,850 | 58,906 |
| Non-productive (age 0-6 or +55) | 30,860 | 30,860 |
| Elite socio-economic groups 1-3 | 2,970 | 2,970 |
| Workers for state projects & production of value-add goods | **13,320** | **7,264** |
| **Total** | **100,000** | **100,000** |

**Table 7.2: Consolidated manpower profile of a representative population sample of 100,000[1020]**

The bar chart below summarises the same data presented above and illustrates the percentage distribution of the population collated by work category in Egypt and Cyprus.

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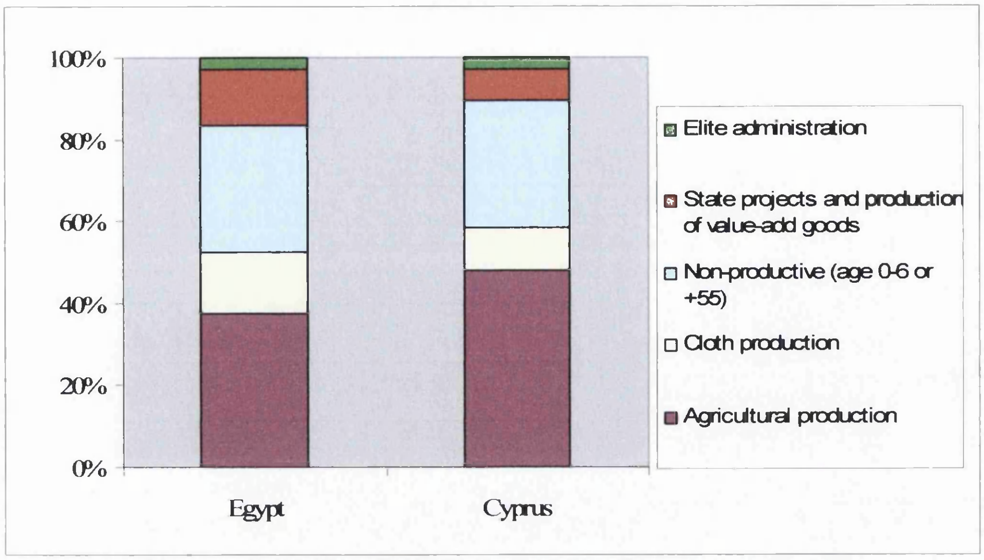
[1017] See earlier discussion in Section 3.2.2 and the analysis in Reports 3.6a-3.7f inclusive in AGCALC.

[1018] The skeletal remains of 68 individuals from non-élite cemeteries at Amarna indicate they had a poor diet and had suffered a harsh working life. Although only a small sample of the skeletons has so far been examined, the results indicate that only 2 lived beyond the age of 50 (Zabecki 2007: 53-59, in particular Table 3 and Figure 13 and Kemp 2008: 43-44).

[1019] The size of the élite has been discussed previously in Section 3.4.1 in Chapter 3 when discussing the socio-economic profile of LBA society to determine the demand for cloth and clothing.

[1020] Élite socio-economic groups 1-3 are defined in Chapter 4, Section 4.4.1.




**Percentage distribution of the population by work category.**[1021]

In summary, whilst it is not possible to know how the élite prioritised the allocation of manpower resources, it is possible to highlight the available choices that they could make between supporting state and élite needs. In part this would have been a factor of the absolute size of the population. In Egypt, the élite would have greater choice because with an estimated population of 2.2 million the non-basic workforce amounted to 293,000. Cyprus with a maximum population of 200,000 and possibly as low as 150,000, would have had a non-basic workforce between 14,528 and 10,900 individuals.[1022]

Cyprus, due to its small population, had less potential opportunity to use the harvest to support added-value production. This thesis assumes that smelting of copper and alloying with tin to make bronze was an added-value activity. Chapter 6 has shown that to make the 10,478 kg of copper from Cyprus found on the Ulu Burun wreck would require 4,535 man-years of effort. To alloy this amount of copper with the 1,000 kg of tin found on the Ulu Burun wreck to make bronze would require a total 5,207 man-years of effort. The demand for copper was high in the LBA (discussed below in Section 7.2.2) and as has been shown in Chapter 6. Lead isotope testing demonstrates that the majority of oxhide ingots in the Eastern Mediterranean have a

[1021] As domestic building and pottery manpower as a proportion of the total population was so small they have been excluded from this bar chart.

[1022] An Island census of Cyprus in 1881 by the British authorities gave a population of 186,000 (Knapp 1997a: 37). For the analysis and assumptions for population levels used in this thesis see Report 6.10 in BRONZECALC.

Cypriot provenance.[1023] Therefore this thesis concludes most of the copper produced in Cyprus was for export and not for internal conspicuous consumption and that it was possible that this was exported through gift exchange.[1024] Evidence for price variations will be discussed Section 7.6.2. However the conclusion can be drawn at this point that visualisation of an *oikos* economy by Bücher, Weber, and Finley's is clearly inappropriate in terms of scale for the economy of the LBA.

The scale of the Egyptian non-basic workforce clearly demonstrates the potential strength of the Egyptian economy but even this seemingly vast workforce of 293,000 was at risk of famine as a result of low inundations. The impact of a succession of failed harvests and the strategies employed to minimise their effect will be discussed in the following section.

## 7.2.1 Vulnerability of the economy due to failed harvests

A drop in the yield of crops from the annual harvest could significantly reduce the absolute non-basic workforce of Egypt and for Cyprus, 293,000 and 10,900 respectively, as these have been calculated on the basis of an average harvest.[1025] The economies of the LBA were vulnerable to poor harvests and even Egypt suffered at relatively frequent intervals from poor harvests when the Nile inundation was too high or too low, too early or too late. These factors that made the agrarian sector vulnerable were outside of the control of the ancient farmers and explain the regularity of economic recessions. Poor harvests provide a possible explanation for the economic collapse thought to have been one of the reasons for the instability of Egypt in the First, Second and Third Intermediate periods. Failed harvests are also

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[1023] Gale 1999: 110-121, Stos-Gale and Gale 2002: 359-262, Gale and Stos Gale 2005: 117-131, and Stos-Gale *et al* 1997: 83-123

[1024] It is not surprising that the gifts in the Amarna letters from the king of Alašia to the Egyptian Pharaoh do not mention any fine goods being sent, only copper. The king of Alašia differentiates copper into two categories, fine copper (refined), and copper alone (presumably black copper of the quality of the copper ingots on the Ulu Burun wreck). In the letters the king of Alašia asks for fine goods in return. For example in EA34 he asks for an ebony bed, 2 horses, pieces of linen and linen clothes, ebony, sweet oil, in return for 200 talents of copper. Other Amarna letters from other kings to Egypt include high value metals (gold and silver) and lapis lazuli among other fine wares. Possibly this means that the king of Alašia did not have access to fine goods and resorted to sending different grades of copper.

[1025] This has been assumed on the basis that Egypt and Cyprus' populations were 2.2 million and 150,000 respectively as discussed above.

thought to be a contributory factor for the economic depression in the LBA/EIA transition.[1026]

In Egypt the height of the Nile inundation is totally dependent on the annual rainfall in Ethiopia and Uganda (see again Figure 3.9 and Figure 7.1) and can be approximated to a normal distribution around the mean.[1027] The variation of rainfall in rain-fed dry farming regions such as Cyprus can also be approximated to a normal distribution around the mean.[1028] Ethnographic and historic yields of staples show they can be approximated to a normal distribution around the mean.[1029] Moroccan tree ring evidence from the last 1000 years shows that severe droughts occurred in 6 of the last 10 centuries.[1030] The evidence demonstrates that seriously poor harvest yields did occur.[1031]

The two principle strategies to minimise the effects of below average harvests were to reduce rations down to a level where people could still work without severe malnutrition, followed by distribution of a strategic stock of crops stored in state granaries. These strategies will be examined in the next section. It was not possible to increase the marginal land under cultivation in the current year of the poor harvest as there would not have been enough time to produce more food. Maintaining production of marginal land in times of adverse mini-climate changes may have been

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1026 Hassan 1997: 1-23.

1027 Wilkinson 1997: 83, Figure 5. The historic records of the Nile inundation show that the variation can be considered as a Normal distribution (see statistical analysis in Reports 3.35-3.36 of AGCALC).

1028 Harris 1991: 24 and van Oosterom, Ceccarelli and Peacock 1993: 307-311 show that between 50-70% of the variability in wheat and barley yields are a function of rainfall. Harris' computer simulations show a good correlation between measured rainfall and cereal yield and predicted yields in both Syria and Southern Russia (Harris 1991: 31). Tunisia with average rainfall of $<350$ mm, has a marked linear correlation between barley yield and rainfall (Wilkinson 1997: 77). Yields of Barley measured for the period 1980-1986 A.D. at Aleppo in Northern Syria follow the same pattern as annual rainfall (Wilkinson 1997: 83, Figure 5). Modern records of rainfall records for Upper Mesopotamia show a normal variation around the mean (Wilkinson 1997: 71, Figure 2). Other factors that impact cereal yields: are the seasonal distribution of rainfall, length of growing season, and temperature. Although no direct evidence is cited for Cyprus, its annual rainfall and summer temperatures are similar to the temperature and rainfall bands measured in the studies above. I think it is reasonable therefore to approximate the Cypriot grain yield to the normal distribution of the annual rainfall around the mean.

1029 For full references and analysis of the yield data see Reports 3.10-3.14 and 3.40-3.41 in AGCALC.

1030 Wilkinson 1997: 75 citing Stockton and Meko 1990: Figure 1.15.

1031 The occurrences of major famines are known from a number of sources of which the best known are: the causeway leading to Unas's mortuary temple with graphic drawings of starving people, the autobiography of Ankhtify describing the problems of famine in the First Intermediate Period, and Papyrus B.M. 10052, 10. 5-8 of the Late Period reflecting the scarcity of barley during a famine.

possible through increased investment in irrigation canals. The first action to take following a poor harvest was likely to have been to cut the rations and therefore lower the daily calorie intake.[1032] There is, however, a point of diminishing returns if rations are lowered to a level where first morale and then health of the agrarian workers is significantly impacted.[1033] The situation becomes even more critical when, as a result of a succession of bad harvests, hunger becomes so severe that the seed corn has to be used for food. In this situation the following year's crop is jeopardised. Consuming seed corn seems a very unlikely occurrence except perhaps in times of war when the state infrastructure collapses. A more pragmatic solution would have been to import grain either through trade or by gift exchange between ruling élites. The Amarna letters show that grain was given in periods when either the harvest had failed or in periods of war when the internal redistribution process had broken down.[1034]

## Strategies available to minimise the impacts of failed harvests

To evaluate the impact of these yield variations on the LBA economy a spreadsheet model was created for the analysis (hereafter called FAMINE and GLUT). The model represents 100 years of harvest for Egypt and Cyprus. The base assumption for the model is that the yield of the harvest varies in proportion to the level of rainfall in Cyprus and, in the case of Egypt, the level of the Nile.[1035] The model is interactive so that any assumption can be varied but to simplify the discussion two

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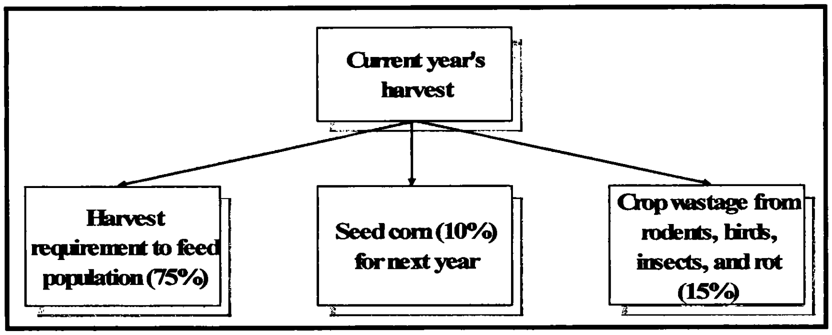
[1032] At a local level those workers living close to rivers or marshes may have supplemented their diet with more protein (fowl and fish). However stocks of wild foods can easily be destabilised by over-culling (Hassan 1997: 12). Wild food would not have been a solution at a macro level as there would have been limitations on transport and food preservation in the Bronze Age.

[1033] Dennell 1979: 121-135, Martin, Goodman and Armelagos 1985: 227-280, and Southgate 1981. All emphasise how a poor diet exacerbates the endemic problems of parasitic and intestinal infections.

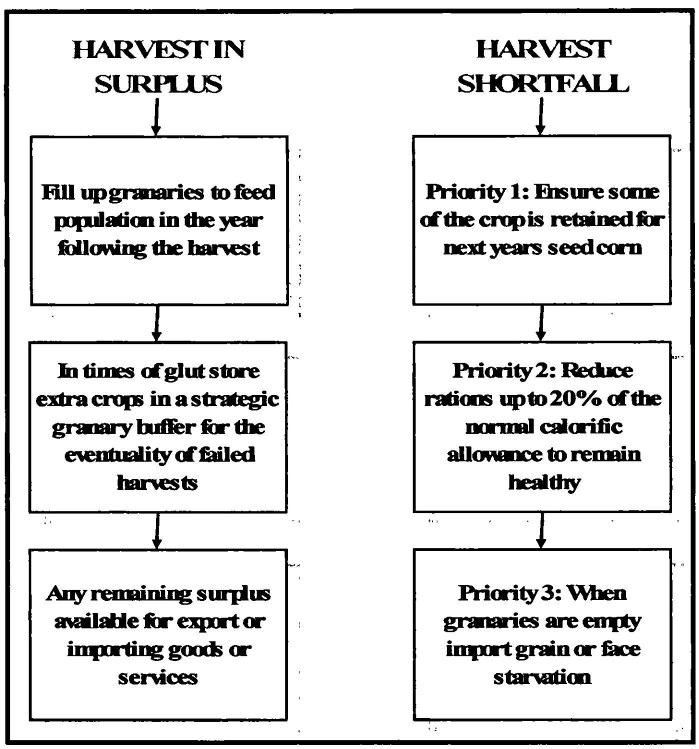
[1034] Examples of requests for grain gift exchanges are given in the Amarna Letters. The request for grain from the king of Byblos, Rib-Addi (EA83, EA85, and EA125), a statement of shortage when Sumura was under siege (EA91 and EA105), and a final desperate plea that Sumara had fallen and if grain was not given by the king then the city of Gubla would follow (EA131). A letter (EA98) describes the loss of a cargo of grain transported by ship from Byblos to Ugarit. A letter (EA224) from Šum-Add[a] to the king opens by stating that he and his ancestors had always responded to requests for grain, implying that he would now in a time of need want the favour to be returned.

[1035] This thesis assumes the grain yields in Reports 3.10-3.14 and 3.34 in AGCALC vary randomly between the best and lowest harvests based on historic and ethnographic evidence (worksheets BEST YIELD and WORST YIELD in AGCALC). Random generated percentages are multiplied by the energy requirements between these limits for Egypt and Cyprus. For Egypt in the example evaluated would range between 53,468 and 167,442 kcals/100,000 population respectively (see Reports 3.44b FAMINE AND GLUT Egypt). For Cyprus the range is 41,914 and 172,548 kcals/100,000 population respectively (see Reports 3.45b in FAMINE AND GLUT Cyprus).




**Schematic 7.2 : Input assumptions used in FAMINE and GLUT.**

The current harvest had to meet the annual calorie requirement to feed the population which for Egypt and Cyprus was 86,065 million kcals/100,000 population taking into account sedentary and active calorie requirements.[1041] Taking into account wastage and seed corn requirements the energy required to be harvested each year for Egypt and Cyprus is 109,299 and 105,908 million kcals/100,000 population respectively (hereafter referred to as average harvest).[1042] Some years would have produced a surplus of which some would have been stored in granaries as a buffer to be used in the years following that were significantly below average. The options open to the administration are summarised in the Schematic 7.3 below.

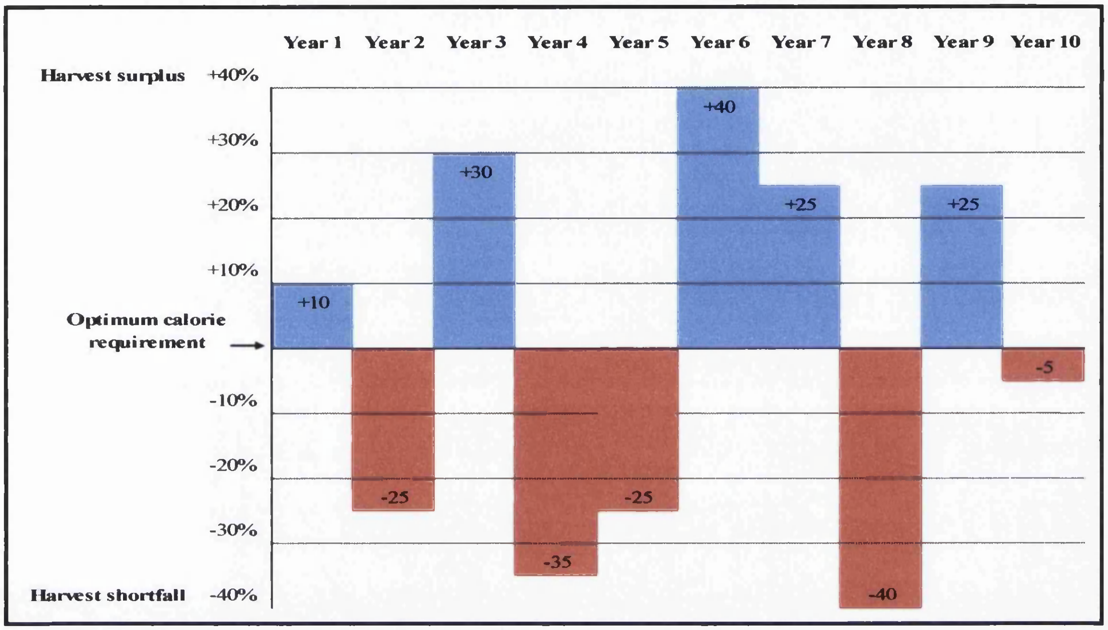



**Schematic 7. 3 showing the options open to the administration for harvest surplus or shortfall.**

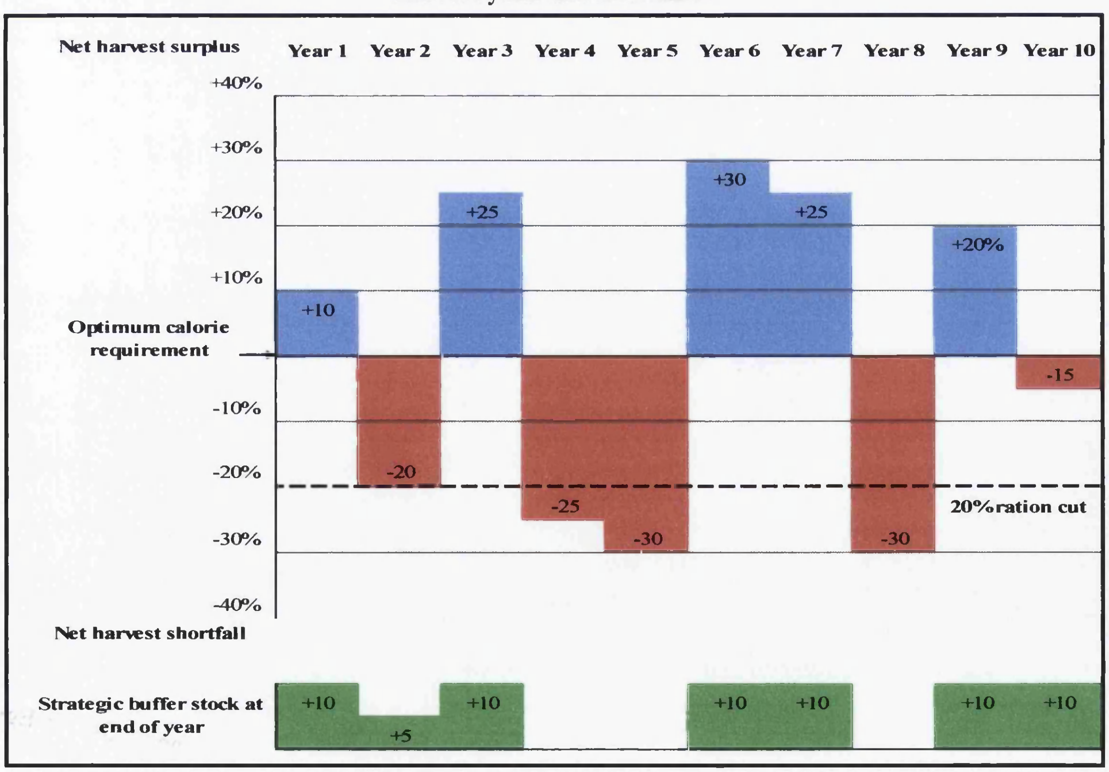
[1041] See earlier discussion in Section 3.2.2 and Report 3.8e.

[1042] Egypt would be higher because the proportion of grain in the Egyptian diet is considered to be higher than Cyprus as discussed previously in Section 3.2.3.

To illustrate how these options would work out in practice, a simplified example is given covering a 10 year period. The schematic below represents the varied harvest yields that could be expected from Cyprus and Egypt assuming both were normally distributed around the mean as discussed above.




**Schematic 7.4 illustrating a 10 year variation in harvest yield varying around an average harvest yield and no buffer.**




**Schematic 7.5 illustrating the resulting surplus or shortfalls using a strategy of a 10% strategic stock buffer.**

The schematic above illustrate how a strategic buffer stock level of 10% of an average would alleviate but not eliminate the effects of poor yields.[1043] It assumes that at the start of year 1 the strategic buffer stock (hereafter referred to as buffer) was full i.e. 10% above normal needs. In year 1 the extra 10% yield above requirements could be used for exports or to feed imported labour for state projects. In year 2 a shortfall of -25% in harvest yield can be alleviated by 5% taken from the 10% buffer enough to feed the population and leave a 5% buffer for year 2. The shortfall in calories of -20% is on the threshold of a population moving from being hungry to true malnutrition.[1044] This -20% level would be the maximum level to which the administration could allow the ration levels to fall. In year 3 a harvest surplus level of 30% means that the buffer can be restored to 10% and there is 20% for additional state investments and trade. However in year 4 a catastrophic harvest of minus -35% yield means that the entire buffer will be used and the shortfall becomes critical at -25% which is 5% below the minimum threshold level discussed above. This means the administration would have to import the equivalent of 5% of an average harvest to avoid the onset of starvation conditions. Year 5 with another bad harvest of -25% moves the situation into famine also requiring imports of grain. Year 6 shows an above average harvest of +40% from which the buffer is restored leaving a short term opportunity for importing goods or labour. Years 7-10 follow the same principle as those in years 1-6.

This simplified example highlights a number of important considerations when analysing ancient agrarian economies. If the population was constrained to a below average calorie intake for several consecutive years the result would be steady debilitation of the health and strength of manual workers on both the land and the bronze industry. The example also highlights a major problem for the administration of variable harvests in that any buffer stock can only ameliorate poor yields for a minimal period, and any gluts have to be used that year either for importing goods or short term imported labour. Even in Egypt grain stored outside of granaries was

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[1043] At a local level those workers living close to rivers or marshes may have supplemented their diet with more protein (fowl and fish). However stocks of wild foods can easily be destabilised by over-culling (Hassan 1997: 12). This would not have been a solution at a macro level however with limitations on transport and food preservation in the Bronze Age. The Egyptians would have been better placed with expertise in drying fish as discussed earlier in Section 3.2.4 relating to protein in the ancient diet.

[1044] Department of Geography (University of Liverpool) 1997: 185-188.

rapidly wasted through actions of insects, birds, and rodents. To have enough granaries for long term storage of gluts would be prohibitively expensive as illustrated in the estimated manpower of 923 man-years to build one Ramesseum.[1045] It is sometimes assumed that if the harvest yield was normally distributed the gluts would balance out the below average harvests.[1046] However the gluts cannot be stored for any long period outside granaries for reasons stated above and the 10% buffer can be quickly consumed so the effect of gluts can disappear in one year. The bulk of the glut harvests was probably exported within 12-18 months and therefore over time the effects of poor harvests will be more pronounced than years of plenty as the gluts cannot be stored for longer periods without an exorbitant associated expenditure of building and managing granaries.

The FAMINE and GLUT model (Reports 3.44-3.45) prioritises the available harvest in line with the Schematics 7.2-7.5 above. For each year the model ensures that a 10% seed corn requirement for next year is maintained, up to 10% of the harvest is stored in granaries to alleviate any harvest failure the following year, and in the years of bad harvests the model will allow rations to be cut up to the equivalent of 20% of an average harvest. The results of modelling 100 years using these parameters shows that Egypt and Cyprus might fail to meet the optimum energy levels to feed the population in 32 and 40 times out of every hundred respectively.[1047] As discussed in the simplified example, even more serious would be the number of times runs of two and three harvests that failed to meet 80% of the optimum energy levels of an average harvest.[1048] For Egypt runs of two consecutive poor harvests would be expected to occur only on average 12 times, and a run of three consecutive years 3 times every 100 years. For Cyprus the results show that runs of two consecutive poor harvests would be expected to occur only on average 16 times, and a run of three

[1045] The assumptions and analysis is given in Report 5.8f in SHELTER.

[1046] The random generated yields around the mean in the 100 years modelled in FAMINE and GLUT suggest that every 56 years the harvest will fail to meet the optimum requirement to feed the population and 46 will exceed the optimum. This is reasonable considering the sample size is only 100 years.

[1047] The model assumes that an average harvest will produce the optimum calorie requirements to ensure that the population maintains a healthy diet.

[1048] It has been assumed that he administration first course of action would have been to reduce rations by 20%.

consecutive years 5 times every 100 years. This suggests that Cyprus was more prone to famines than Egypt if no action was taken to import supplementary food.

It might be thought that increasing the buffer stock would be a better strategy. However increasing the buffer stock to 15%, with the same ration cut of 20%, only marginal improvement is obtained. In this case the number of times the Egyptians would have failed to meet the optimum food energy levels would only be reduced from 32 to 27 years out of every 100. For Cyprus the number of times that the optimum food energy levels would have been reached would only have been reduced from 40 to 38 years out of every 100 respectively. This suggests that the optimum strategic buffer would have been between 10 and 15%.[1049] For runs of 2 and 3 years for different buffer stocks see the table below.

| | Buffer stock set at 10% | | | Buffer stock set at 15% | | |
|---|---|---|---|---|---|---|
| | Total no. of years where harvest failed to reach average yield | Run of 2 years where harvest failed to reach average yield | Run of 3 years where harvest failed to reach average yield | Total no. of years where harvest failed to reach average yield | Run of 2 years where harvest failed to reach average yield | Run of 3 years where harvest failed to reach average yield |
| Egypt | 32 | 12 | 3 | 27 | 10 | 3 |
| Cyprus | 40 | 16 | 5 | 38 | 15 | 4 |

**Table 7.3: Consolidated manpower profile of a representative population sample of 100,000**

Variable harvest yields would probably have stimulated a thriving market, exporting staples in times of glut and importing staples in periods of poor harvests. This need for importing grain on a regular basis is significant when considering the scale of interregional trade. The archaeological record shows that significant quantities of metals, pottery, luxury goods, and pithoi were moving around and between the Eastern, Central, and Mesopotamian trading networks. What does not show up in the archaeological record is the trade in invisible staples which, as has been calculated, is likely to have been a major factor. LBA textual evidence shows grain was easily transported by sea as demonstrated by the letter from the king of Hattusha to the king of Ugarit demanding that he provide a ship and crew to transport 2000 measures of grain to be shipped from Murkish to Ura in southern Anatolia. Egypt in the reign of

[1049] This is confirmed using higher levels of buffer stock as given in Reports in FAMINE and GLUT. A summary of the findings is give in Reports 3.44d and 3.45d.

Merneptah also shipped grain by ship to Anatolia to relieve famine.[1050] The large jars found on the Ulu Burun wreck could easily transport staples safely by sea transport.[1051] In Section 7.2.3 it will be demonstrated that LBA ships could carry large volumes of grain in water tight storage jars such as those found on the Ulu Burun wreck. It was important to keep the grain dry to prevent it from swelling and endangering the ship. It is interesting to speculate whether the relatively low quantities of luxury goods found in the early part of the LBA in Cyprus was due to payment in grain rather than luxury goods.[1052]

## The infrastructure costs of a state redistribution system

Many scholars have stated that a key requirement for the operation of the ancient economy, of which the LBA was no exception, was a state redistribution process. To provide an analytical framework for the discussion and conclusions on the nature of the ancient economy in Chapter 8 an attempt will be made to estimate the infrastructure costs of running a state redistribution process. This section will show that these costs were significant as they covered the cost of administration, losses within the system, transport of staples, building and maintaining granaries. It is not intended to give a definitive number for the cost of redistribution as it is impossible to calculate this with so many factors unknown. However it is possible to place some boundaries around the redistribution process that will help discussions on size of the state investments required to support the administration. The cost estimates to make the granaries (covered below) does not represent an annual expenditure which in

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[1050] The Hittite measure of grain was the *kor* which equals 300 *qa*. In imperial units one litre is approximately equal to one *qa*. The request for 2,000 measures would represent 600,000 litres which is approximately equal to a weight of 450 metric tons (Astour 1965: 255). A second millennium letter shows that 300 metric tons of grain was shipped up the Euphrates from Emar to Mari. Another Mari letter states fifteen metric tons of wheat, source not stated but probably Egyptian, was shipped north along the coast to Ugarit (Silver 1985b: 65).

[1051] Hirschfeld 2005: 103-108 and for Cypriot storage jars in particular see Pilides 1996: 107-127. For an extensive review of the textual evidence for trade in 'invisibles' in the Bronze Age see Knapp 1991: 21-89. Leemans 1960a: 19-37 provides evidence that cuneiform lexical lists indicate that 'invisibles' were included and traded in the Bronze Age. Larsen 1987: 48, Figure 5.1 summarises western Asiatic invisibles (including grain) traded from and to northwest Syria, Anatolia, and the Levant.

[1052] Keswani 2004: 137,139 shows LCI-IIB tombs have increased luxury goods with a dramatic increase in particular of bronze weapons. In particular Keswani 2004: Tables 5.6-5.10 powerfully demonstrates that the statistical (Pearson's r correlations and other techniques) used to create a wealth index increased significantly in Cypriot élite chamber and shaft tombs over the period from LCIA to the LCIII period (1650 to 1100 B.C.). For a simple explanation of Pearson's r correlation see Plonsky 2006.

reality would have probably been amortised, in the case of Egypt with its favourable climate, over several generations. Nevertheless manpower costs for meeting Egypt's population growth and general maintenance would not have been trivial.

Redistribution of staples was a widespread practice in the Aegean and Eastern Mediterranean. In Cyprus large LC IIC pithoi from the Pithos Hall building X in Kalavasos-Ayios Dhimitrios had a total capacity of between 35,000 and 50,000 litres for the storage of olive oil for redistribution or exports.[1053] The extensive corpus of Linear A and B tablets found in the Aegean palaces clearly show the importance of the supply of rations to the workers of both the Minoan and Mycenaean cultures.[1054] In Anatolia vast granaries at Hattusha testify to the investments made to support their redistribution processes. The German Institute of Archaeology excavations at Hattusha has excavated a complex of grain silos 118 m by 30-40 m, containing 32 chambers in two rows, with a total capacity of 7000-9000 $m^3$.[1055] This is enough grain to feed 20,000 – 30,000 people for a year (Figure 7.2).[1056] Yon suggests that the eighty Canaanite commercial jars excavated in the warehouses in the harbour of Minet el-Beida in Ugarit, and many others in Ras Shamra itself, is evidence that grain and oils were traded in large quantities by ship in the LBA.[1057] In Egypt state granaries are first attested in the 3rd Dynasty but were probably in place before this.[1058] An Eleventh Dynasty sarcophagus from Deir el Bahri describes the 'Great Granary' which had five silos to store grain.[1059] The type of grain stored is not stated but the table below shows between 12,000 and 20,000 adults could be fed depending on whether wheat or barley was stored.[1060]

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[1053] Discussed previously in Section 3.2.4 relating to the production of olive oil in Chapter 3.
[1054] Bennet 1985: 231-249, Chadwick 1972: 100-116, Halstead 1987b: 519-529, Halstead 1992/3: 57-86, Killen 1985: 241-305, Shelmerdine 2006: 73-86, and the seminal work of Ventris and Chadwick 1973. See Flouda 2000: 213-245 for a detailed description of the need and the operation of the nodule accounting and control system of redistribution centres in Pylos.
[1055] German Institute of Archaeology, *The Excavations at Hattusha*, created 15/09/2002, last updated 26/6/2004, accessed 25/7/2006, available from http://www.hattuscha.de/eng/themen/05-forschung/silokomplex/forschung-silokomplex.htm.
[1056] Giorgadze 1987: 251-256, Heltzer 1987: 237-250, and German Institute of Archaeology, *The Excavations at Hattusha*, created 15/09/2002, last updated 26/6/2004, accessed 25/7/2006, available from http://www.hattuscha.de/eng/themen/05-forschung/silokomplex/forschung-silokomplex.htm..
[1057] Yon 2006: 142-143, plate 30.
[1058] Eyre 1987b: 167-221, Katary 2007: 188 and Wilkinson 1999: 128.
[1059] Cairo Museum reference 28083 and text translated by Balanda 2003: 413.
[1060] This analysis assumes that the Egyptian diet was as shown in Report 3.4a which contributed 351 kg of carbohydrates/man/year. The calculation in Report 3.4a in AGCALC assumes that the Eleventh

| | heqat | litre | kg wheat | kg barley |
|---|---|---|---|---|
| Silo 1 | 645,550 | 3,098,640 | 2,382,855 | 1,451,159 |
| Silo 2 | 326,620 | 1,567,776 | 1,205,620 | 734,223 |
| Silo 3 | 45,600 | 218,880 | 168,319 | 102,507 |
| Silo 4 | 233,400 | 1,120,320 | 861,527 | 524,670 |
| Silo 5 | 667,770 | 3,205,296 | 2,464,873 | 1,501,108 |
| **Total** | **1,918,940** | **9,210,912** | **7,083,194** | **4,313,667** |
| **No. of men fed per year assuming rest of diet maintained** | | | **20,180** | **12290** |

**Table 7.4: Number of adults that could be fed from the 'Great Granary' at Deir el Bahri**

Of a similar order is Kemp's estimation of the Ramesseum granaries on the West Bank at Thebes which could store rations for up to 20,000 people for a year.[1061] Even these measures did not prevent famine occurring in Egypt.[1062] This was mainly due to the fact it took time to replace the strategic buffer and therefore famine could last beyond the actual period of drought. Janssen described the role played by granaries for food redistribution in Egypt:

> Egypt's economic structure as a whole can best be described as organised on the principle of redistribution, which means that the surplus of peasant households was collected by the authorities, state and temple, in order to be redistributed among particular sections of society: officials, priests, the army, necropolis workmen and so-on.[1063]

Not all of the redistribution process was in the hands of the state with many granaries within the protection of forts such as Mirgissa in Nubia.[1064] The Ramesseum and other temple estates show that they had a significant role to play as well as the contributions from private estates.[1065]

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Dynasty *heqat* was equivalent to 4.8 litres (Quirke 2003a). The densities of dry wheat and dry barley used throughout this thesis are 769 kg/m$^3$ and 609 kg/m$^3$ respectively.

[1061] Kemp 1991: 195-196.

[1062] I have not been able to trace any textual evidence of famine in Egypt for the period under study. I take the position that for the reasons given in Chapter 3, Section 3.1.2 that the height of the inundation was totally dependent on the rainfall falling in Uganda feeding the White Nile. All metrological evidence indicates there is a variation around the mean which would inevitably mean in some years the inundation height would be low or late in arriving. Both factors would have a detrimental impact on the harvest causing a possible famine.

[1063] Janssen 1983: 253.

[1064] Others being the granary of the Middle Kingdom military fort at Askut with a granary capacity of 1,632 m$^3$ (Ezzamel 2002: 6). It could be that these granaries were built to meet a military strategic need. They were sited within important locations within Egypt's empire and therefore facing the possibility that supply rations could have been interrupted in periods of uprisings and unrest.

[1065] The Egyptian king distributed land to members of the élite that had been a loyal servant. King Ahmose gave a large estate to an 'officer of ships' which was 60 arouras in size (220 ha) (see Sethe 1906: 6.7-6.9, Kemp 2006: 329, and Kitchen 1982: 128-129). The estates could be dispersed to relatives or to paid officials to manage them on behalf of the owner. Shares of these estates were allocated to them as recognition of their loyalty that could be inherited and passed on from one generation to another (Eyre 1994: 114-115).

The scale of the granaries is discussed next and the role they played in the operation of the ancient economy. The textual and archaeological evidence for the redistribution of grain is much greater for Egypt than Cyprus and this discussion concentrates on this evidence. This section starts with an overview of the Egyptian evidence. Estimates will then be made for both regions on the size and number of granaries required to support storage of seed corn, wastage allowance, day to day redistribution of non-basic rations, and finally the strategic stock granaries. Finally overheads incurred in managing the redistribution process will be discussed.

## Scale of granaries required to sustain the Egyptian economy

The large scale of the Egyptian redistribution system is demonstrated by the volume of crops, 1,019,823,455 kg needed annually to feed the total population.[1066] This would require a storage capacity of 1,796,123 m$^3$ to feed the total population as shown in the table below.[1067]

| Crop | Egypt Wt kg | Egypt Vol m$^3$ |
|---|---|---|
| Barley | 14,640,060 | 24,040 |
| Emmer wheat | 4,879,819 | 6,346 |
| Pulses | 13,702,488 | 27,405 |
| **Total/100,000** | **33,222,367** | **57,790** |
| **plus wastage 15%+seed corn 10%** | | |
| Barley | 4,162,175 | 6,834 |
| Emmer wheat | 1,386,349 | 1,803 |
| Pulses | 3,896,276 | 7,793 |
| **Total/100,000** | **9,444,801** | **16,430** |
| **Harvest buffer to smooth out harvests at 10%** | | |
| Barley | 1,880,224 | 3,087 |
| Emmer wheat | 626,617 | 815 |
| Pulses | 1,759,876 | 3,520 |
| **Total/100,000** | **4,266,717** | **7,422** |
| **Total storage requirements** | | |
| Barley | 20,682,459 | 33,961 |
| Emmer wheat | 6,892,785 | 8,963 |
| Pulses | 19,358,641 | 38,717 |
| **Total/100,000** | **46,933,884** | **81,642** |
| **Total/popl'n** | **1,032,545,456** | **1,796,123** |

**Table 7.5: Egyptian storage requirements for grain and pulses as defined in Section 6.2.1**

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[1066] This includes 10% for seed corn and 15% for wastage.

[1067] For the full analysis see Reports 3.44F-3.44N in FAMINE and GLUT. Using rations for a Deir el-Medina family as given by Janssen 1979: 512 a much higher volume requirement is obtained of 2,787,840 m$^3$. This should only be considered as an upper limit as it is generally considered that the Deir el-Medina rations were far higher than those received by a typical workers family in Egypt at the time. The affluence of the Deir el-Medina workers is clearly demonstrated with details of bartering within the Workmens Village and at the local markets on the River bank. Without a surplus grain from their rations this barter would not be possible.

Managing this estimated volume of corn would have been a staggering logistic feat even by modern standards although the Ancient Egyptians have throughout their long history shown that they were capable of performing complex logistic tasks. To try and comprehend what this means in terms of the number of granaries and the effort required to transport this volume, quantitative comparisons have been made using archaeological evidence from extant granaries and the carrying capacity of donkeys.

### Numbers of granaries required and manpower required to build and maintain them

We do not know the proportion of the grain stored in central granaries to that stored in distributed granaries in the rural hinterland. To appreciate the scale of this storage requirement estimates have been made assuming all were stored in either Ramesseum or Amarna granaries. In practice granaries of a wide range of capacities would have been built.[1068] If all the granaries were the size of the Ramesseum then 109 granaries would be needed to store the 1,796,123 $m^3$ of crops required to feed the total population of Egypt at the end of the New Kingdom and would require 100,607 man-years to build them. If they were the size of the Amarna granaries then 189,066 granaries would have been required taking 63,337 man-years to build them.[1069]

### Distribution costs

To minimise transport costs state granaries the size of the Ramesseum probably would have been built close to the centres where added-value production was carried out and the workers and associated dependents lived. Ramesside texts show that tariff for grain transport on the Nile amounted to approximately 10% of the cargo.[1070] The majority are likely to be the size of the Amarna granaries or even smaller on the

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[1068] For a detailed analysis of the size of granaries as a function of house size and house type houses owned by the élite in Amarna see Mihoko 2002: 110-111, Table 1. The designs of the Ramesseum, fortress granaries, and Amarna granaries were covered earlier in Section 5.3.3.

[1069] These granaries would not be built in one year but even if amortised over several generations would be a significant overhead. The analysis of the number of granaries required and manpower to build them covered previously in Reports 5.1-5.10 in SHELTER. The Amarna granaries reflect a more simple ergonomic design in terms of 'build time' but the volume they could hold was limited by the structural limitations of a domed roof. Any country wide redistribution system would require a mix of both designs. Note that at Amarna a large granary for production of loaves and providing grain for brewing has been excavated (223 x 218 m) was built on an industrial scale (Kemp 1994: 133-153 and Kemp 1995: 437-438.

[1070] Janssen 1994: 41-47.

farms themselves.[1071] They could then be more evenly distributed along the Nile valley minimising distribution costs between the point of production and consumption.[1072]

Report 3.21f in AGCALC and the table below show the harvest requirement to meet the rations for basic and value-add workers. In addition a 10% buffer stock to smooth out harvest fluctuations is included.

| Per 100,000 population | Percentage | Wt kg | Vol m³ | Area ha |
|---|---|---|---|---|
| Crops in state granaries for value add workers | 15 | 7,040,083 | 12,246 | 5,660 |
| Crops stored in state granaries to minimise famines/gluts | 10 | 4,693,388 | 8,164 | 3,773 |
| Grain/pulses stored in rural granaries | 75 | 35,200,413 | 61,231 | 28,298 |
| **Totals** | **100** | **46,933,884** | **81,642** | **37,731** |
| **Total population 2.2 million** | **Percentage** | **Wt kg** | **Vol m³** | **Area ha** |
| Crops in state granaries for value add workers | 15 | 154,881,818 | 269,418 | 124,512 |
| Crops stored in state granaries to minimise famines/gluts | 10 | 103,254,546 | 179,612 | 83,008 |
| Grain/pulses stored in rural granaries | 75 | 774,409,092 | 1,347,092 | 622,562 |
| **Totals** | **100** | **1,032,545,456** | **1,796,123** | **830,082** |

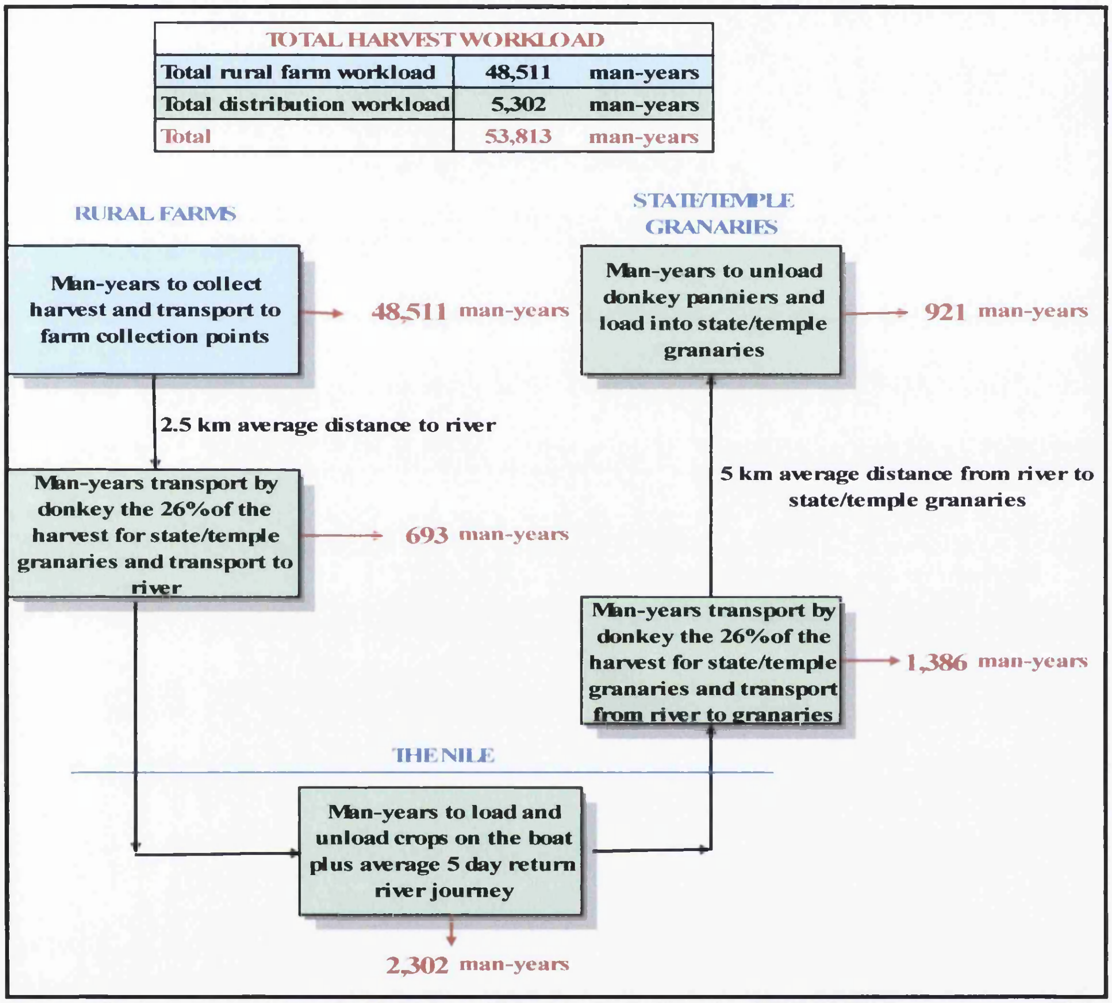
**Table 7.6: Summary of the weight, volume and area of land under grain and pulses cultivation for the total Egyptian population estimated to be 2.2 million at the end of the New Kingdom correlated by the proportions stored in local rural and state granaries**

Donkeys are capable of carrying 75 kg of grain/pulses in panniers which hang either side of the animal. To transport this quantity of grain and pulses from the fields would require 625,785 return journeys to supply a population sample of 100,000.[1073]

The implications of the scale of redistribution and what might be the practical limits of a redistribution economy for a state the size of Egypt will be discussed in the next chapter. An attempt will be made here to estimate the manpower effort needed to support this transport of grain to the granaries. Despite the uncertainty of some of the assumptions the following estimate does highlight the scale of the operation. It has been assumed that on average the grain destined for state or temple granaries was transported 2.5 km from local farm collection points to the river and 5 km from the river unloading point to the state/temple granary.[1074] The manpower effort to collect the harvest and take it to the farm threshing centre has been estimated previously to

[1071] The estimated construction costs of the Ramesseum and Amarna granaries are given in Report 5.8-5.9 in SHELTER.
[1072] A recent publication on building the Giza pyramids (Romer 2007) clearly shows the effectiveness of the control processes and optimisation of resources that enabled them to complete its construction within 14 years.
[1073] A donkey could carry 75 kg (Mumford 2006: 48, fn 38 and Heltzer 1977: 203-211). The number of donkey journeys for the total population would have been 13,767,273 journeys.
[1074] The approximate length of the Nile valley floor from Elephantine (Aswan) and Memphis (South of Cairo) is 850 km. It is assumed that most rural villages would be closer to the water than the desert and a mean distance chosen to carry grain and pulses to granaries is 2.5 km.

be 24 man-days/ha.[1075] This gives a workload of 48,511 man-years working on a total growing area of 622,562 ha supporting rural granaries.[1076] Shipping costs and transport costs to and from the river would amount to 5,302 man-years; giving a grand total of 53,813 man-years.[1077] A summary of the transport process is given in the schematic below.




**Schematic 7.6 summarising the elements of workload moving the harvest crops to storage within a single month**

Food left lying in the fields would have been subject to wastage losses from rodents, birds, fungus, and insects and it would have been important to store the harvest as quickly as possible. Scheduling this workload within a period of four weeks, the total number of individuals required would have been twelve times higher, resulting in a requirement for 645,752 individuals. Chapter 3 has shown that the total number of

[1075] Analysis and assumptions given in Report 3.22a in AGCALC.
[1076] For the full analysis used in this section see Report 3.20i-3.20k in AGCALC.
[1077] The Amiens Papyri show that grain ships could carry 76 m$^3$ of crops (Janssen 2004: 28, table 1). The same papyri states that the crew required for this size of vessel was 15 (Janssen 2004: 29).

farmers supporting the total population of 2.2 million is 818,510 individuals. The total people working on the land during harvest would therefore be 1,464,262 individuals. Only a proportion of the farmers themselves could have been involved with transporting the food to the granaries as they had other commitments to fulfil such as irrigation, weeding, and tending other crops and livestock.[1078] Even if half the farmers could have been involved directly in satisfying this harvest transport 'spike' workload and therefore reducing the demand for corvée labour the organisation of the harvest must have been a major logistical feat by the administration. The army could easily be transferred to assist in this short term activity but the scale of the requirement would mean the corvée labour would have to be directed to the task whether the individuals wanted to or not.[1079] Acceptance of this annual task is perhaps indicative that the ordinary worker saw himself as a servant of the state. This supports the view that the workers themselves were embedded in the institutions of the state.

**Overhead costs**

In addition to the permanent agrarian labour plus the additional corvée labour discussed above there would also have been a significant overhead to the process. Scribes recorded and audited the flow of grain from the harvest fields through to the milling process at state bakeries. They also determined what level of tax could be expected from the harvest taking into account the level of the Nile, the area and type of land under cultivation.[1080] After the harvest, scribes also audited and recorded the actual yield of the current year's harvest measured in *hekat* (4.78 litres). Marked wood-scoops ensured consistency of measurement, making the harvest yield auditable across the whole country. Scribes checked the grain flow from the farm to the river for transport by boat.[1081] Other scribes checked it in at the state, regional or

[1078] As discussed previously in Chapter 3 there is a labour overhead if a strategy of multi-cropping compared with monoculture farming is followed.

[1079] Harvest was only one of these embedded state tasks, monumental religious building construction and maintenance or repairs to the basin irrigation system would also be in the same category.

[1080] The detailed analysis of the Heqanakht Papyri by Allen 2002 clearly shows the scribal effort that was invested by the ruling élite in tax assessment, planning, and auditing to avoid corruption.

[1081] A fragment of a wall painting in the 18th dynasty tomb of *Wnsw* in the Louvre, invoice number N.1430 shows large quantities of grain being loaded in boats for transport to the granaries of the Temple of Amun. The inscription reads "Filling of the barges with the divine offerings for … loading barley, corn and wheat, the silos they are overflowing, the heaps reach their mouth … the barges are filled heavily. The grain spurts out" (Barbotin 2006: 34).

temple granaries and continued to monitor its progress through the storage, bread, and beer production processes.[1082]

## Variation in the size of the non-basic workforce

### Impact due to the annual variation in harvest yields

Of particular interest to the operation of the ancient economy is how fluctuating harvests impacted on the size of the manpower required satisfying the non-basic needs of maintaining the state infrastructure, added-value production, and conspicuous consumption needs. Referring back to the hierarchy of needs in Schematic 7.1 these requirements can only be met when the basic needs have already previously been satisfied. The greater the flow of added-value goods and luxury goods within any trading network area, the more wealth was generated. How wealth and value is defined in an ancient context will be covered in Section 7.6. The number of years of possible famine was quantified in Section 7.2.1 and the options open to the administration to minimise the impact of this. This section will quantify the scale of the manpower which could be supported for non-basic activities during the years when the harvest yield fluctuates around the average harvest yield. If the state had excess food in any year it had the option of importing manpower for non-basic activities. As noted, because of the problems of the storage of crops when the harvest yield exceeds the average, the use of this surplus entirely for importing additional labour from neighbouring regions would have been limited. It is probable that only a proportion of this potential to import labour was utilised due to the time it would have taken to organise and bring in labour from neighbouring regions. In terms of manpower costs there is little or no difference between feeding imported manual workers or slaves taken as booty from military campaigns, or indigenous manual workers. A more likely outcome for those years of plenty would have been importing a mix of high value commodities such as copper and tin ingots, luxuries, and labour for non-basic activities. Imports of luxuries and commodities would have the effect of increasing the level of trade between states of the Eastern Mediterranean and further afield.

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[1082] Kemp 2006: 171-172. This scribal activity was twofold; as a check against corruption and as an integral part of the state bureaucracy to plan, control, and supply workers for added-vale production and state or temple infrastructure projects.

Despite the uncertainties of the exact proportions allocated to importing additional labour, luxury goods, and commodities, an analysis of the surplus years in FAMINE and GLUT will provide an upper limit for the potential level of additional manpower some of which would be available for short term additional added-value production in the times of glut.[1083]

This potential additional non-basic workforce is analysed in four stages. The first category estimates the case when no added value could take place. The second estimates the likely number of years that a workforce engaged on non-basic activities could have been supported in years when the harvest is below normal but the threshold where their work has to cease due to severe malnutrition has not been reached.[1084] The third determines the number of years that the workforce for non-basic activities can be supported in the years where the harvest produces an average yield. The fourth category takes the case of an above average harvest yield which would allow the élite to choose between importing luxury goods and commodities, and/or importing some additional manpower for non-basic activities as noted above.

The results from FAMINE and GLUT for these three categories of harvest for Egypt and Cyprus are shown in the below. This demonstrates that in a random sample of 100 years with varying harvest yields, Egypt had a greater resilience to withstand adverse growing conditions than Cyprus. The analysis shows that Egypt and Cyprus could support some form of non-basic activities for 83 and 66 years in every hundred following a strategy of implementing a state granary buffer of 10% and a ration cut of 20% in years of harvest shortfall. The number of years where no non-basic activities could be supported from the harvest despite the use of a state granary buffer of 10% and a ration cut of 20% in years of harvest shortfall would be 17 and 32 out of every 100 for Egypt and Cyprus.[1085] This could be alleviated however by importing grain which will be discussed in the next section when discussing copper production constraints in Cyprus. The options open to the regional ruling élites and the consequences of what this says about a possible interregional staples market

[1083] The analysis uses the same random yield parameters in the analysis of Section 7.2.1.
[1084] For example the total energy requirement
[1085] See earlier discussion in Section 7.2.1on the impact of widespread malnutrition and starvation.

within the LBA economy will be discussed below in 'Options to avoid copper production capacity constraints in LBA Cyprus' in Section 7.2.2 .

| Number of harvests in any 100 that enabled non-basic activities to take place without taking other measures such as importing grain | Egypt | Cyprus |
|---|---|---|
| | Number of years/100 | Number of years/100 |
| Category 1: No. of years where no non-agrarian activity could be supported | 17 | 34 |
| Category 2: Less than average but with some non-basic activity | 15 | 6 |
| Category 3: Average harvests | 29 | 21 |
| Category 4: Above average harvests | 39 | 39 |
| Totals | 100 | 100 |

**Table 7.7: Potential for added-value activities in Egypt for a 100 year period**

It was not solely the proportion of years available for non-basic activity that was an indicator of relative economic wealth, as the absolute size of the population was also a dominating factor.[1086] The table below dramatically shows that when the non-basic manpower is summed cumulatively for the total 100 year period, the economic strength of Egypt was significantly greater than that of Cyprus. Comparing the cumulative sum of non-basic manpower shows that Egypt had 12 times the opportunity for non-basic activity than Cyprus.[1087]

| Sum of all non-basic manpower for a 100 year period | Egyptian man-years | Cypriot man-years |
|---|---|---|
| Harvest category | | |
| Category 1: No. of years where no non-agrarian activity could be supported | 0 | 0 |
| Category 2: Less than average but with some non-basic activity | 2,744,346 | 40,308 |
| Category 3: Average harvests | 9,032,804 | 276,255 |
| Category 4: Above average harvests | 20,485,036 | 1,723,869 |
| Totals | 32,262,186 | 2,040,432 |

**Table 7.8: Potential for added-value activities in Cyprus for a 100 year period**

This clearly supports the case that Egypt was a core from a world-systems perspective because the scale of its economy, with its inherent non-basic discretionary spends, enabled it to dominate other regions through both military and economic measures.[1088] It is the combination of this military strength and the

[1086] As noted above the population of Egypt was ca. 2.2 million compared with Cyprus was ca. 150,000.

[1087] As discussed above this would not be totally expended on importing labour but it did give Egypt the opportunity to import large quantities of luxuries, commodities, or invest in infrastructure projects such as the spectacular temple complexes in Thebes.

[1088] The Amarna letters clearly show that Egypt was the ascendant power. Egypt gave substantial gifts in commodities and luxuries to vassal states but the obligations expected by Egypt in return, clearly demonstrated they were peripheral states and acknowledged the supremacy of Egypt. This is at odds with Wallerstein's own position on world systems in that his model stresses the economic not the political entity of the core and therefore different from empires and city states (Wallerstein 1974b: 15). The work of Chase-Dunn and Hall 1997 demonstrate that the application of the world system model is useful in analysing ancient economies as the model links politics, economics, geography into a unified construct. As Schloen 2001: 85 especially footnote 34 points out Wallerstein later agreed that his model was applicable to pre-modern economies. This thesis supports that both political and capacity to support foreign expeditions that copper resources could be easily plundered in places such as Timna in modern day Israel.

## Summary for Section 7.2

The approach of defining the number of workers that could be afforded from the size the harvest surplus has provided an objective way of identifying the proportion of the population that could be dedicated to non-basic activities. The hierarchy of needs shows that the scale of the non-basic workforce for the total population, 293,000 workers in Egypt was huge compared with other regions of the Eastern Mediterranean such as Cyprus with 10,900 workers engaged in non-basic activities.[1089] This section has shown that the size of non-basic workload was not minimalist as hypothesised by Butcher, Weber, and Finley. An economy with this size of workforce that could be dedicated to added-value manufacturing or state infrastructure projects can never be considered as minimalist in nature as proposed by Bücher, Weber, and Finley. Production of goods and services in the LBA, and perhaps never in the case of Pharaonic Egypt, was not organised on an *oikos* scale where the scale of production was set by the minimum needs of the household alone. Instead production of commodities, particularly metals, oil, and glass ingots was at an unprecedented level as demonstrated by the Ulu Burun and Gelidonya wrecks.[1090]

From a world-systems perspective again Egypt was the prime economic core of the Eastern Mediterranean. Egypt had two choices how to invest its non-basic manpower. It could direct the workforce to increase its trading competitiveness through state infrastructure projects that increased its productivity. Piramesses is one example by centralising its industrial processes in one area optimised movement of workers and materials. Others were investment in larger ships and harbour facilities, large scale granaries, and building networks of canals to control the vagaries of the

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economic factors should be considered when analysing the economy from a world systems perspective.

[1089] This number of family dependents that are too young or too old to work equate to 678,920 and 46,290 for the total population of Egypt and Cyprus respectively. For analysis and assumptions see Reports 3.1a and 3.1e in AGCALC.

[1090] For a discussion on the possible link between the blue glass ingots found on the Ulu Burun wreck and ingot moulds found in Amarna and Piramesses see Nicholson, Jackson and Trott 1997: 143-153.

inundation.[1091] Alternatively it could invest the non-basic manpower in conspicuous consumption projects such as temples and political/ religious prestige projects such as moving the capital from Thebes to Amarna in the reign of Akhenaten. It is the balance between these two alternatives that goes to the heart of the formalist-substantive debate. A balance that favoured the latter would indicate that the ruling élite were conservative and intent on underpinning their internal powerbase and this is a substantive attribute. This topic will be returned to when the evidence will be examined for the degree to which the Egyptian economy was embedded within social relations and institutions.

### 7.2.2 The scale of the metals trade in the LBA Eastern Mediterranean

The debate as to whether the LBA economy was 'minimalist' and/or 'primitive' will be continued in this section specifically evaluating the metals trade which was the largest added-value industry in the LBA. The discussion will examine the size of the demand for these metals. Building on these findings an assessment will be made of whether the ancient economy was capable of responding to fluctuations in the supply and demand for metals. The substantive view was that transport was too costly and demanded too much effort to respond to market conditions in particular price fluctuations, which are implicit in the workings of formalist economies.[1092]

The purpose of the first part of this section is to assess the scale of the bronze industry for the period 1400-1200 B.C.[1093] Bronze has been chosen for analysis from all the other possible added-value activities for analysis because it was the one commodity that was a critical requirement for the operation of the LBA economy.

[1091] For a review of canal networks supporting agriculture in the Fayum see Eyre 1994: 57-80. See Willcocks 1889 for a detailed engineering perspective of the operation of the canal network, and the basin irrigation system, in use in Egypt from the Pharaonic period up to the mid-Nineteenth Century A.D. For the developments in Egyptian ship design capable of carrying large cargoes see, Landström 1970, Fabre 2005: Faulkner 1940: 3-9, Ward 2000b, and Ward 2004. See Kemp and O'Connor 1974: 101-136 for a detailed review of New Kingdom harbours and quays support the Nile transport artery. For a review of the Egyptian outlets for sea transport, see Gophna 2002: 418-421 and for outlets to the Red Sea in particular see Fabre 2005: 76-86.
[1092] Humphreys 1969: 187, 194.
[1093] I have used the term 'bronze' as a generic term that would also have included arsenical bronze as discussed in Section 6.1 of Chapter 6. By this period very few tools or weapons were made of pure copper and most bronzes were made using a tin to copper alloy mix of 1 to 10.

Without bronze for tools and weapons, the rival power blocks would not have been able to compete in military and economic terms.

The period under study 1400-1200 B.C., though relatively peaceful, came about because of mutually balanced levels of military power between the Egyptians, Hittites, Mitanni, and the growing power of the Assyrians.[1094] To ensure the balance of power was maintained, large investments in the latest designs of weapons were made by the regions with standing armies and this resulted in a large demand for bronze.[1095] The archaeological record shows that by the 19th Dynasty in Egypt, particularly in the reign of Ramesses II, the Egyptian copper mines in Timna were working to full capacity. An obvious supplier of copper was Cyprus but it would have been difficult for Cyprus to meet the demand from all the major powers. Textual evidence shows that Cyprus had exported copper in the LBA to Mesopotamia, the Hittites, and Egypt either through trade and/or gift exchange.[1096] Cyprus also exported significant quantities of olive oil if the document of a Cypriot merchant shipping 600 jars of oil to Ugarit is representative of the scale of exports.[1097] Cyprus had large forests ideal for making charcoal for their smelting centres but also suitable for making ships. Two of the Amarna letters (EA35 and EA 38) informs us that the King of Alašiya had sent wood to Egypt.[1098]

To estimate the demand for metals this section will be in two parts. Part A will compare the cost of producing copper in Cyprus and the Egyptian mines at Timna

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[1094] The notable exception was the Battle of Kadesh in 1294 B.C. between the Hittites and the Egyptians in the Reign of Ramesses II.

[1095] Spalinger 2005 particularly chapters 10-13. Spalinger provides a helpful overview of the interregional politics of the period 1400-1200 B.C. Using a wide range of evidence and quantitative excurses he discussed the importance of the latest designs of weaponry combined with mobile battle strategies based on chariots and large cohorts of archers supporting traditional infantry. All of this would have increased the demand for copper.

[1096] Gifts from the King of Cyprus to the Pharaoh: Amarna letters EA33 (200 talents of copper and 10 talents of fine copper), EA34 (100 talents of copper), EA35 (500 talents of copper), EA36 ([...] + 70 talents remain), EA37 (5 talents of copper), and EA40 (14 talents of copper and 3 talents of fine copper). A full list of gift exchange correspondence to the and from the King of Cyprus can be found in Knapp 1996b.

[1097] Heltzer 1978: 152-153. Cyprus also exported olive oil to Egypt (Ahituv 1996: 41-44), Syria (Callot 1987), and Crete (Blitzer 1993: 163-172). As Ugarit, Syria and Crete are in the olive oil Mediterranean belt the Cypriot oil must have been of a high quality to make it worthwhile.

[1098] In the fragmentary Amarna letter EA36 the King of Alašiya writes that he will build large number of ships (California Institute for Ancient Studies 2001. *The Encyclopedia of El Amarna Research Tool.* Accessed 3rd July 2008. Available from http://www.specialtyinterests.net/eae.html. California Institute for Ancient Studies,). Caution is required about placing too much emphasis on this much quoted text as Moran 1992: 109 considers it too fragmentary for translation.

plus the costs of alloying the copper to produce bronze. This is important because Neo-classical economics suggest that the cost of production of a commodity is reflected in its price which is inversely proportional to the demand. In other words the higher the price (which equals cost if no profit is built into the transaction) then the lower the demand. This will allow conclusions to be made on how the Eastern Mediterranean ruling élites sourced bronze. If the ruling élites did not follow the rational choice of the cheapest supplier it will indicate that other substantive factors are involved in the supply and demand process. Part B will estimate the demand for copper and tin in the LBA by examining the bronze requirements for three sectors of the LBA economy requiring the greatest quantity of bronze: the military, agriculture, and skilled craftsmen. Part C will outline the textual evidence for the scale of the metals trade.

## Part A: Cypriot copper production

This part demonstrates that Cyprus was a 'low-cost' copper producer in the Eastern Mediterranean but limited by the size of its population. In Chapter 5 the large scale of copper mining in Cyprus and Timna was covered. The archaeological record shows that Egypt was mining and smelting copper at Timna on a large scale particularly in the Ramesside period.[1099] LBA copper mining and smelting in Cyprus was concentrated around the pillow lavas of the Troodos Mountains.[1100] The manpower requirement analysis in BRONZECALC has shown that the cost of production of copper in the Troodos Mountains in Cyprus was significantly lower than copper made in Timna, 0.433 and 0.827 man-years per kg.[1101] This made Cypriot copper 52% of the cost of mining and smelting copper in the Egyptian mines at Timna.[1102] This difference in cost becomes even more dramatic when determining the effort and scale of operations required to make the 10,478 kg copper found on the Ulu Burun wreck. If the copper cargo was made in Cyprus the manpower needed

[1099] Rothenberg, B. 1999.
[1100] Both Egypt and Cypriot production was covered in Chapter 6, Sections 6.2-6.4.
[1101] The full analysis and assumptions are given in Chapter 6 and Reports 6.2.1-6.5.2 in BRONZECALC.
[1102] This is almost entirely due to the ease of extracting the copper sulphide ores by open pit excavation compared with deep shaft and tunnelling mining necessary at Timna to extract the copper nodule ores. Covered previously in Sections 6.2 in Chapter 6.

would be 4,535 man-years, in Timna it would be 8,666 man-years.[1103] Tin would have been imported by both regions to make bronze and as noted the most likely source would have been Central Asia.

Another approach for comparing the manufacturing costs between Egypt and Cyprus is to compare the agricultural costs of Cyprus and Egypt in supplying the grain to feed their respective metal workers and those manpower costs required to make a given weight of copper.[1104] Dividing the copper manpower rate by the agrarian rate for Cyprus and Egypt will give normalised cost ratios for comparison that takes into account in one go the differential costs of both copper and food production.[1105]

For most of the New Kingdom one sack of barley (77 litres) was valued at 2 *deben* of copper (0.182 g), a value ratio of 1 to 2. Reports 3.21a in AGCALC shows that the manpower plus prorated overheads to make one sack of barley was 0.059 man-years in Egypt (AGCALC Report 3.31a). The cost of making 2 *deben* of copper produced at Timna was 0.1506 man-years (BRONZECALC Report 6.1d), a manpower ratio of 1 to 2.55. The manpower plus prorated overheads to make one sack of barley in Cyprus was 0.076 man-years (AGCALC Report 3.31b). The cost of producing 2 *deben* of copper in Cyprus and shipping it to Egypt was 0.0788 man-years (BRONZECALC Report 6.1e) giving manpower ratio of 1 to 1.04 when comparing a sack of grain to the production of 2 *deben* of copper. This clearly shows that it was 2.5 times as expensive to produce copper in Timna as in the Troodos Mountains in Cyprus using barley as the value comparator. This reflects the relative ease of mining for copper sulphide ores in Cyprus compared with the deep shaft mining of copper ore nodules in Timna despite the higher cost of producing grain in Cyprus.[1106]

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[1103] The analysis and assumption set for mining and smelting tin can be found in Reports 6.1.4, 6.2.3, 6.3.1, and 6.4.5 in BRONZECALC.
[1104] The formalist view of the LBA economy would need to recover as a minimum the cost of production over the long term. In Section 7.6 below the question of how the ruling élites addressed value, price, and profit will be covered.
[1105] This approach of differential cost analysis forms the basis of modern manufacturing cost accounting practices.
[1106] This was discussed previously in Chapter 6, Section 6.2-6.3.

**Capacity constraints in Cypriot copper production**

The implications of copper production in the Egyptian mines at Timna being more than twice as expensive as that in Cyprus in terms of the cost of feeding their respective metal workers, raises the possibility of production capacity constraints in Cyprus. This section will examine the options facing the LBA Eastern Mediterranean if there was a 'World' shortage of copper. If Egypt had chosen to source its copper in Cyprus on expense grounds this would indicate a rational formalist approach to making economic decisions. Matters such as security of supply or even the wish not to be beholding to another region would be indicative of a more substantive introspective consideration more in keeping with a substantive approach to the economy.

The copper ore resources in Cyprus supported a large scale mining operation in Cyprus up to the 1990's A.D. despite copper being mined there for over 4000 years.[1107] The constraining factor for Cyprus in the LBA that limited its production output was the absolute size of the population which this thesis has as noted above, to be between ca. 150,000-200,000 for the period of peak LBA production 1300-1200 B.C. Earlier discussions in Section 7.2 show that the workforce available for non-basic activities for these population levels would be within the range 10,900 to 14,528 workers. Large scale copper mining, charcoal production, smelting, and bronze production required significant numbers of men and the non-basic workforce could easily be swallowed up by these activities leaving no manpower for state infrastructure needs and conspicuous consumption needs of the élite.[1108]

**Options to avoid copper production capacity constraints in LBA Cyprus**

If Cyprus wanted to increase copper production, the first option would have been to increase the productivity of the agrarian workforce so that more food could be grown to support a larger mining workforce. Food production could be increased by land clearance made easier with the introduction of bronze axes compared with earlier copper axes that easily became blunt. This would have enabled mixed farming to be

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[1107] Most of the large scale open cast mines were closed in the period 1985-1999 A.D. as they were less competitive than other major world producers of copper.
[1108] Previously covered in Section 7.2 in this chapter, Reports 3.1a in AGCALC, and Reports 6.2-6.8 in BRONZECALC.

intensified and labour productivity increased by moving from hoeing to ploughing as the norm.[1109]

Another option would have been to import grain so releasing agricultural workers to support the copper industry. As noted above there is evidence from the Ulu Burun wreck evidence that large Canaanite jars and the pithoi could have carried staples safely without the risk of being contaminated by salt water.[1110] In Cyprus there is a low level of conspicuous consumption artefacts and monumental buildings until the LCIIIA. This is unexpected given the probable levels of copper exports. We can speculate that this may have resulted from accepting payment for the copper in food staples not fine goods. A contrary argument could be that the fine organic goods such as cloth were imported for conspicuous consumption which has become invisible in the archaeological record. The Amarna letters (EA33-EA40) between the King of Alašiya to the King of Egypt using the honorary title "My brother" indicates that he was the head of the high status élite in Cyprus ca. 1350 B.C. that was comparable to the other great powers of the period. This indicates there were high status élite prior to LCIIIA in Cyprus if Alašiya equals Cyprus.[1111] This has an important implication for LBA trade as staples, now invisible in the archaeological record, would have meant that there was a much greater scale of trade in the LBA.[1112]

**Summary**

The cost analysis above shows that, from a cost perspective Cyprus would be the source of choice for copper. Egypt was the other large scale producer in the Eastern Mediterranean but the cost of producing the copper was 191% higher than in Cyprus and 180% higher mining the copper in Timna and then alloying with tin to make bronze from Central Asia at Piramesses. The archaeological record shows that Cypriot oxhide ingots are widespread having been found from as far as Sardinia in

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[1109] Knapp 2008: 79-81 and Manning 1993: 44-47. This is not without its problems as manpower has to be provided for growing, collecting, and distributing fodder as discussed earlier in Chapter 2.

[1110] For evidence of grain transport in the LBA on the Nile see Janssen 2004. For containers that could have transported perishables see Sherratt and Sherratt 1991: 363-364 and Crewe 2007: 12-13. Archaeo-botanic evidence show the Uluburun carried olives (one Canaanite jar contained at least 2,500 olives), pomegranates, grapes, figs, nuts, almonds, pine, pistachio, acorns, coriander, cumin, sumac seed, grain, and pulses.(Haldane 1990: 55-60, Haldane 1993: 352-355, and Pulak 2001: 36-37).

[1111] This thesis assumes that Alašiya was Cyprus and the arguments of this long standing debate have been summarised by Knapp 1985b: 231-250. For a contra argument see Merrillees 1987 and Merrillees 1995: 17-22.

[1112] This topic will be returned to in Section 7.5.1 discussing harvest gluts.

the West to the Levant in the East, and possibly Egypt. If the low-cost increased demand, Neo-Classical economics indicate that Egypt should have imported copper in bulk from Cyprus. The fact they continued large scale operations in Timna while importing some copper from Cyprus shows that either Cyprus could not meet the demand for copper or market forces as we know them today were not in operation and Egypt's economy was substantive.

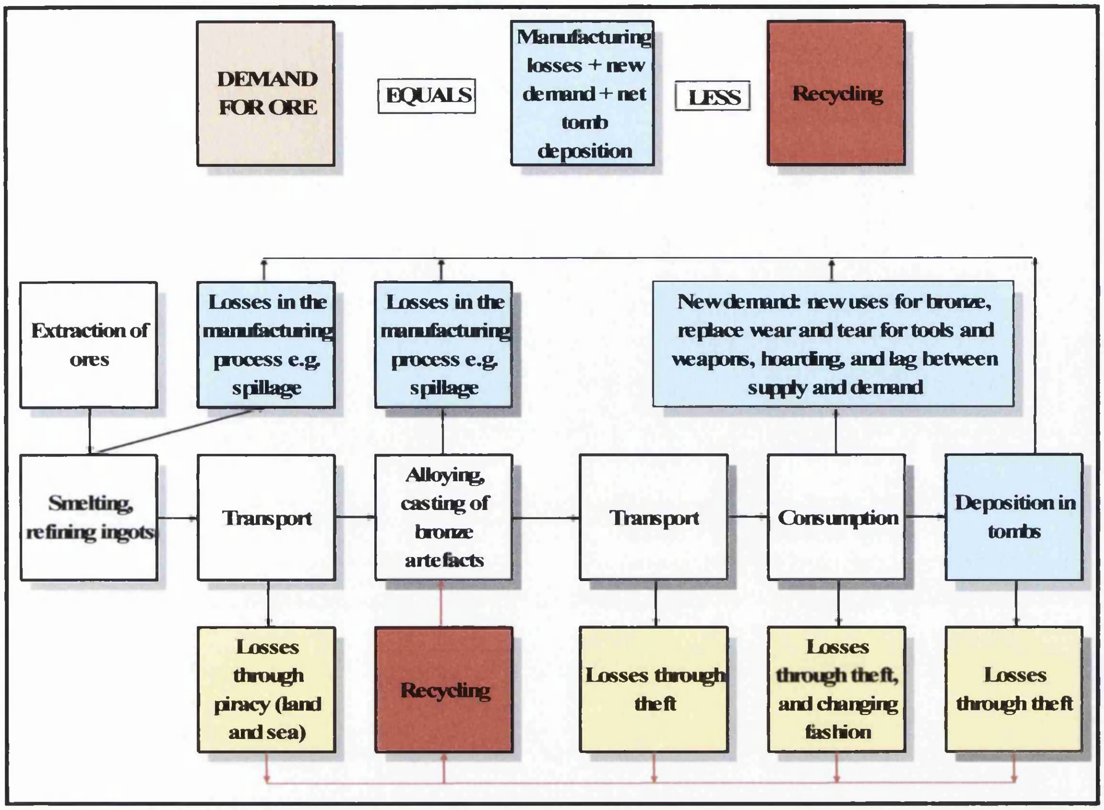
## Part B: The demand for bronze in the Eastern Mediterranean

Part B will estimate the scale of demand for copper and tin used to make bronze. Three case studies will quantify the scale of demand for bronze to supply the weapons for the army of Ramesses II, the bronze required to support the agrarian sector of the LBA economy, and the bronze necessary to supply craftsmen with tools. Assumptions have been made for all three cases but they are conservative and provide the minimum case for the absolute demand for copper in the LBA. The variation of price of these metals will be analysed in part B to determine if there is a correlation between all three. This would indicate that the LBA metals trade followed the law of supply and demand, an attribute of a formalist economy.

### Quantitative case studies for the demand of bronze in the period 1400-1200 B.C.

Numerous examples of the design of bronze tools and weapons are known from the archaeological record but not the absolute demand. Bronze can be re-cycled and so the archaeological record understates the demand.[1113] To estimate the absolute demand for bronze is impossible due to the number and complexity of the variables illustrated in Schematic 7.7 below.

[1113] Karageorghis and Kassianidou. 1999: 171-188 for evidence found within the precincts of the Kition Temples. See footnote following relating to the Gelidonya wreck.




**Schematic 7.7 illustrating the complexity of the demand process for copper.**

The most difficult area to quantify in antiquity is the scale of recycling. The archaeological record clearly shows that when artefacts were life expired recycling was common.[1114] Even in the modern world with the growth of the Chinese economy demanding increasing quantities of copper only 18% of world annual demand is satisfied by recycling.[1115] We can only guess at the recycling level in antiquity but with artefacts less prone to changing technology and fashions, it is reasonable to say that recycling was only two to three times higher, say a maximum of 50%.

In this section estimates have been made of the demand for bronze in two stages. First the weights of a representative range of weapons and tools from the LBA are estimated. The number of weapons and tools used has been estimated from what is suggested by the textual, archaeological, epigraphic, and tomb painting evidence. Three quantitative examples have been chosen to demonstrate the scale and value of the bronze from the perspective of the user of the bronze. Egypt has been chosen as representative of the larger economies in the Eastern Mediterranean and will be used

[1114] See Bass 1967b: 84-117 for a catalogue of hundreds of pieces of scrap bronze showing the size of the recycling industry in the Bronze Age.
[1115] Giurco and Petrie 2007: 1-3.

to estimate the demand for bronze to make the weapons required to arm the army of Ramesses II and the manufacture of bronze tips of ploughs and hoes, masons' and carpenters' tools.

**Case study 1: The Egyptian Army at the time of Ramesses II**

It is suggested that the weapons used by the Egyptian Army for the Battle of Kadesh were made from copper and tin mined specifically for battle. They would obviously have been produced over time, many from recycled bronze. Nevertheless the growth in the size of the standing army in the reign of Ramesses II would have led to a significant demand for bronze that would not have been satisfied by recycling. The estimate of bronze used for the organisation of the army and the weight of the bronze weapons employed are given in the attached footnote.[1116] As the weights of artefacts are not recorded in most museum collections careful estimates have been made from the photographs and drawings. To estimate weights of artefacts I have converted the two dimensional reproductions into approximate bar and cylindrical shapes and from these calculated the volume. Multiplying the volume by the density of bronze (8100 kg/m$^3$) gives an estimate of the weight. See Report 6.9.2 in BRONZECALC for an example of my estimation of the weight of a thigh length bronze scale corselet which I have given as 6.1 kg.[1117] The analysis shows that the weight of bronze of the

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[1116] For an informative overview of the weaponry at the end of the 18th Dynasty/beginning of the 19th Dynasty see Darnell and Manassa 2007: 58-90. Estimations for the weights of the Egyptian weapons have drawn upon various sources, the measured weight of excavated weapons excavated from the Uluburun and Gelidonya wrecks (Yalçin, Pulak and Slotta 2005: 621-623), and estimates made from drawings of LBA weapons in and Babón 2003: 161-200, Bass 1967b: 103, Figure 115, and McDermott 2004: 129-187). An additional need for bronze in the second half of the New Kingdom was the introduction of helmets for officers, archers, and élite non-commissioned troops from 1479-1425 B.C. Helmets started to be worn post 1294 B.C. by frontline troops but this is later than the battle of Kadesh so has been ignored (McDermott 2004: 138-139). The Sherden mercenaries in the time of Ramesses II are always depicted with helmets (Partridge 2002: 57). Bronze bits for horses have been found in 15th century B.C. contexts in Gaza, Ras Shamra, and Mycene (Azzaroli 1985: 37-39, particularly Figure 19). The ratio of infantry to charioteers is generally assumed to be 1:10 and common to the whole Near East. Administration texts outline the standard equipment for a New Kingdom chariot: one to two bows, two to four quivers holding in total 80 arrows, spear and/or javelin, one axe and shield and in the LBA bronze khepesh swords appeared. For information on the organisation, size, tactics and weapons used by the standing army of Ramesses at the time the Battle of Kadesh I have drawn heavily on the work of Spalinger 2005. For the size of the Army at the time of the battle I have used the analysis of Spalinger 2005: 202-205, 214-230, footnote 16 who estimates the Army to be 30,000-40,000 strong. Kitchen 1982: 140 assumes a full time standing army of four divisions each 5,000 men. In addition he suggests an un-quantified home reserve as well as units stationed in Nubia.

[1117] This compares favourably with a reconstructed Tiryns' hoplite design bronze scale cuirass (top of the hip length) that weighed 4.53 kg (see http://www.larp.com/hoplite/BAarmor.html#armor).

weapon at the time of Ramesses II, assuming an army of 40,000 men, was 50,056 kg which is equivalent to 4.4 times the weight of the all the copper and tin ingots on the Ulu Burun wreck.[1118] Textual evidence from LBA Nuzi shows that scale armour and scale helmets were used by their militia.[1119] If it is assumed that this army was smaller (ca. 30,000) the weight of bronze required would have been 36,530 kg or 3.2 times the weight of all the copper and tin ingots on the Ulu Burun wreck. Assuming 50% of the metal had been recycled, still represents 1.6 times the weight of the all the copper and tin ingots on the Ulu Burun wreck.

This investment in military bronze weaponry was not limited to the Near East. Large numbers of bronze knives, arrow heads, axes, and spearheads have been found in the cemeteries at Sintashta and other fortified settlements in the southern Urals and the Caucuses in MBA/LBA contexts. Finds of bronze fishhooks and bent sickle-like knives attest to the demand for bronze in the agriculture (cf. discussion in case study 2 below).[1120]

**Case study 2: Bronze requirement to support the Egyptian farmers**

The case study estimates the demand for bronze in the agrarian sector of the Egyptian LBA economy. In the New Kingdom copper tips were fitted to the bottom of the ard of the plough (Figure 7.3).[1121] The Gelidonya wreck had many examples of designs for bronze heads thought to have been fitted to wooden shafts and used as hoes (Figure 7.4).[1122] Taking the drawing B48 as representative of a plough head and B54, as a hoe heads the estimated weights are 1.02 and 0.46 kg respectively (Figure

[1118] The weight of the Uluburun copper and tin ingots were 10,480 and 1,000 kg respectively giving a combined weight of 11,480 kg.

[1119] Dezso 2002: 197-199 for lists of weapons with full references. Using Dezos' estimates for the weights of scale armour and helmets used by the Nuzi militia and used in Report 6.9.5 in BRONZECALC. The analysis shows that an army the same size as that of Ramesses II would require 4.7 times the weight of the all the copper and tin ingots on the Uluburun. This is of the same order as that calculated previously for Egyptian weapons. This is further confirmation of the scale of the bronze industry in the Eastern Mediterranean/Western Asia in the LBA.

[1120] Kohl 2007: 153-154, Figure 4.15.

[1121] Stead 1986: 25, Figures 30-32.

[1122] Bass 1967b: 88-95, Figure 106 and Catling 1964: 79-80 are convinced that the bronze heads were fitted to both ploughs and hoes. Many bronze plough heads are found in many museums dated to the New Kingdom (e.g. British Museum EA 50705 with bronze head attached to the plough). Similar designs are attested in Mycenaean mainland Greece, Cyprus, Palestine, and Ugarit (Catling 1964: 81-82 and Bass 1967b:93 citing Deshayes 1960: 139-140).

7.5).[1123] In Chapter 2 on Egyptian agriculture the number of farms per 100,000 of the population was estimated to be 17,889.[1124] Assuming only 25% of the farms had a plough then with an estimated LBA population of Egypt at the end of New Kingdom of 2.2 million the number of ploughs would be 98,390.[1125] Assuming only 25% of the farmers had a bronze tipped hoe the number of hoes would be 9,839. Multiplying the number of ploughs and hoes by their weight (0.46 kg) would give a minimum total bronze weight of 199,928 kg or the equivalent of 17.5 times the copper and tin found on the Ulu Burun wreck.

**Case Study 3: Bronze needed for the tools of Egyptian craftsmen**

This case study estimates the range and diversity of the tools found on the Gelidonya wreck, intact caches of tools found in tombs, and the numerous depictions of Egyptian craftsmen with tools, which show that they were not rare artefacts but should be seen as a commodity. Although the quantity and range of tools used by craftsmen is not known some caches of tools have been found in intact Egyptian tombs (Figure 7.6). A possible approach to the calculation of the bronze required is to carry out 'what if' analyses based on a range of assumptions applicable to New Kingdom Egypt contexts. When considering the range of crafts requiring tools and the extent of Egyptian monumental and domestic building it would be reasonable to assume that not less than 1% and probably a higher proportion of the adult male population had some need for tools.[1126] Using the demographic analysis in Chapter 3, Reports 3.7a-3.7b in AGCALC the male population between the ages 16-50 was calculated as 45.6% of the population. Therefore the number of males would be 501,600 assuming an estimated New Kingdom population of 2.2 million. The table

[1123] B48 has been chosen as best representative of the bronze plough heads on display at the 'Altes Museum', Am Lustgarten, 10178 Berlin-Mitte. My estimates of weight are given in Report 6.9.3 in BRONZECALC.

[1124] For full analysis and assumptions on size of nuclear family see Report 3.21 in AGCALC.

[1125] Twenty five percent is very conservative, particularly for Cyprus with its stony ground, but will be used for this case study to estimate the minimum demand for bronze. See earlier discussion on proportions of farms that had ploughs in Section 3.4 in Chapter 3. The analysis is based on the findings calculated in Report 3.21a-3.21b in AGCALC that there were 17,889 farms in Egypt per 100,000 population.

[1126] This assumption assumes that the majority belongs to the élite but allocated to the craftsmen as the practice of the tomb builders at Deir el-Medina.

below shows the equivalent Ulu Burun wreck tin and copper cargoes assuming each craftsman had tools weighing on average 1-4 kg.[1127]

| Average weight (kg) of tools used per craftsman | Percentage of Egyptian adult males who were craftsmen | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 5 | 7 | 10 |
| | Equivalent number of Ulu Burun copper and tin cargo | | | | |
| 1 | 0.5 | 0.9 | 2.2 | 3.1 | 4.4 |
| 2 | 0.9 | 1.8 | 4.4 | 6.2 | 8.8 |
| 3 | 1.4 | 2.7 | 6.6 | 9.2 | 13.2 |
| 4 | 1.8 | 3.5 | 8.8 | 12.3 | 17.5 |

**Table 7.9: Equivalent number of the Ulu Burun wreck tin and copper cargoes as a function of the % of adult males who were craftsmen and the average weight of tools owned by them**

### Summary

The evidence for these three case studies in part B suggests that the demand for both copper and tin for bronze was significant in scale over a range of applications. New uses for bronze developed in every area of the economy throughout the LBA: military, agricultural, crafts, domestic, and for the conspicuous consumption of the élite. The levels of demand particularly for new uses could not have been satisfied by re-cycling. This section has demonstrated in terms of the scale of domestic and industrial application that the metals trade was not 'minimal'.

## Part C: Textual evidence of the LBA bronze industry

To get some perspective of the size and scale of the bronze trade in the Eastern Mediterranean this section reviews the textual evidence from Mesopotamian and Anatolian textual sources. It is assumed that these regions are typical in terms of the demand and the scale of the metals industry as other regions. Large quantities of tin were transported from Aššur in Mesopotamia to Kanesh (Kültepe) in Anatolia from as early as the second half of the third millennium B.C. where tin and textiles were exchanged for silver and occasionally gold.[1128] The amount of traded tin recorded in Anatolia by Larsen was 13,500 kg or 200 donkey loads.[1129] This would have been equivalent to 1.35 times the tin cargo on the Ulu Burun wreck. Larsen's analysis of the surviving Kanesh texts has estimated that 179,200 kg (eighty tons) of tin mined

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[1127] The full analysis is given in Report 6.9.4 in BRONZECALC.

[1128] Muhley 1973: 206-208, Yener 1980: 29-32, and Yener 2000: 11-12. Özgüç, T. 1986: 34-45 has shown that contact (probably direct or indirect trade) extended from Kültepe to other parts of Central Anatolia, Cilicia, and Southern Mesopotamia (Ur and Fara).

[1129] Larsen 1976: 86. The remains of the Aššur are located on the western bank of river Tigris in Iraq, to the north of the confluence of the Tigris and its tributary the Little Zab. Kanesh was located about 20km north-east of the modern Turkish city of Kayseri.

and smelted in Central Asia was traded into Anatolia over a 50 year period.[1130] Nearly all of the tin mined in the LBA was used to make bronze so assuming an alloy ratio of copper and tin of ten to one it would mean that 1.792 million kg of copper would have been produced. This indicates an annual demand for bronze of 39,424 kg/annum. The weight of the copper and tin cargo on the Ulu Burun wreck was in a 10 to 1 ratio by weight, the same ratio as that required to make bronze. The tin traded into Anatolia in Larsen's study was the equivalent of nearly four times of that carried by the Ulu Burun wreck, a total tin requirement of 4,000 kg. Assuming that copper was required to make bronze then Anatolia would also have required four times the copper cargo on the Ulu Burun wreck, a total copper requirement of 42,000 kg.

Bronze demand had grown significantly since the period of Larsen's textual study (late third Millennium B.C.) perhaps by 2 to 3 times making Anatolia's annual demand for copper and tin equivalent to 8-12 times the total metals cargo of the Ulu Burun wreck.

**Summary**

The textual evidence supports the evidence from parts A and B from this section that the scale of demand for copper was high in the LBA. When the copper from gift exchange given to Egypt by the king of Alašiya (noted above) is factored in with the other regions of the Eastern Mediterranean such as the Aegean that had no indigenous supplies of copper it is easy to see why Cyprus despite its small population and small geographic area had a key role in the LBA economy and the part played by Cyprus will be returned to later in this chapter.[1131]

## 7.2.3 The scale of the LBA marine infrastructure

The objective of this of this section is to see whether there is sufficient evidence to counter the substantive argument that large scale transport was minimal because marine technology was primitive, prone to storms, which limited the movement of bulk goods by land. Three factors will be considered: whether there is sufficient

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[1130] Larsen 1976: 90 with full textual references.

[1131] Lead Isotope and trace metal analysis shows that despite Sardinia having large copper resources of its own, copper ingots were imported into the region in this period (Kassianidou 2005: 331-341, Lo Schiavo 2003b: 15-34, Stos-Gale *et al* 1995: 407-415, and Tylecote, Balmuth and Massoli-Novelli 1983: 63-77, and Zwicker, Virdis and Ceruti 1980: 135-163).

evidence that the foreign artefacts in the archaeological record had arrived by sea, whether the design of ships had evolved so that transport was relatively safe from the effects of storms, and finally whether sea transport was cheaper than land transport.

Long-distance trade had been made easier through developments in sea transport using improved ship designs such as the Ulu Burun, Gelidonya and Port Iria wrecks (Figures 6.6-6.7 and Figures 7.7-7.8). These boats were capable of sailing across open sea, even at night, rather than hugging the coast within the sight of land, requiring overnight stops for refuge in harbours or beaching the boat on the shore.[1132] Despite the risks encountered by sailors and the financial risk taken by the ships' under-writers, states would have had increased confidence in the regular supplies of commodities and manufactured products that were not found within their own regions.[1133]

It was imperative that with this growing demand for both tin and copper to make bronze, reliable marine networks were necessary because the locations of copper ore to meet the demand identified in Part B of Section 7.2.2 are found in only a few regions in the Central and Eastern Mediterranean. As the bulk of copper was provided by Cyprus and tin from Central Asia the general direction of the flow of metals was east to west and the flow of added-value goods was in the opposite direction, west to east. Of particular interest to this study is the movement of oxhide ingots around the Mediterranean and particularly those with a provenance of the copper ore from Cyprus.[1134] These ingots act like pottery as markers of contact (see again Figures 6.3-6.4). Textual evidence show that copper was exported from Cyprus to Syria and Babylonia ca. 1900-1800 B.C., to Egypt in the reign of Tuthmosis III, in

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[1132] This topic is returned to in the following section. For sea routes and navigation in the LBA see Agouridis 1997: 1-24.

[1133] This is not to say long distance trade did not occur in earlier periods. Even in the Neolithic period sea craft had developed sufficiently to move communities and their cattle to Crete (Broodbank and Strasser 1991: 241). The significant shift in the LBA was the increased certainty of supply, which enabled embryonic industries to increase their scale of production to a level not seen before. Canoes and longboats at least by EBA II were capable of travelling 20 km and 50 km per day respectively and were capable of providing an important transport conduit for obsidian into the Aegean (Broodbank 2000: 68-106 and 101-102).

[1134] Lead isotope testing and trace element testing has been discussed previously in Section 6.2.3. Though the claims made by the Oxford Isotrace Laboratory are not accepted in entirety by some scholars the consensus is that the majority of oxhide ingots from the Uluburun and Gelidonya wrecks were made from copper ores mined in the Troodos Mountains (Bass 1967c: 52-83, Gale and Stos-Gale 1986: 81-100, Gale and Stos Gale 2005: 117-131, Galili, Shmueli and Artzy 1986: 25-37, Hauptmann, Maddin and Prange 2002: 1-30, Maddin 1989: 99-106, and Pulak 2000c: 137-157).

the Amarna period, and in the reign of Ramesses II, and to the Hittites ca. 1400-1300 B.C.[1135]

**Improvements in LBA ship design that facilitated an increase in the level of maritime trade**

Archaeo-naval architecture investigations into the hull structure of the Gelidonya, Ulu Burun, and Point Iria wrecks show characteristics of a commonality of design that were too sophisticated and similar to have been three isolated experiments (see again Figure 7.8).[1136] The longevity of the mortise and tenon hull through to the Roman period testifies to the success of this technology and makes it more likely that these three ships were part of a much larger infrastructure of skilled boat builders and sailors. This section provides a brief overview of the unique characteristics of LBA ship design that made a high level of trade achievable.

A key development in ocean going ships was the development of a sturdy keel thought to be introduced in the 15th Century B.C.[1137] The Ulu Burun wreck shows that instead of the keel projecting mainly below the bottom planks of the hull, the keel extended upward into the hull. This robust design would have given immense longitudinal strength as well as protecting the hull when beached or hauled onto the shore.[1138] Hull designs in the Levant and the Aegean had improved with the use of mortise-and-tenon to join the planks similar to later Greek and Roman ships. The

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[1135] Hellbing 1979: 56-7, Amarna letters EA 33, 34, 35, 36, 40 and Knapp 1996b: 67-69, 84. Copper references in letters between the kings of Egypt and Alašiya (Cyprus) are found in EA 33 = 210 talents, EA 34 = 100 talents, EA 35 = 500 talents, EA 37 = 5 talents, EA 40 = 14 talents (taken from translations by Moran 1992: 104,106-107). This is a grand total of 829 talents weighing ca. 23,630 kg (equivalent to 2.3 times the copper cargo on the Uluburun) using the rate that one talent weighs approximately 28-29 kg (Pulak 1997: 251 and Pulak 2000b: 263).

[1136] Fitzgerald 1996: 8-9 and Pulak 1999: 209-238. For an in depth study of the design and construction based on naval architectural principles see the thesis of Lin 2003. All three ships had minimal hull remains due the actions of the tides and infestations of sea animals. The Gelidonya had holes in the remaining planks for wooden pegs (Bass 1967a: 48-50, Figures 46 and 51). The Uluburun remains had a solid keel as well the remains of mortise and tenons, and wooden pegs that would have given a very strong hull (Pulak 1999: 209-238). Similarly the Point Iria has some though limited evidence that it had a mortise and tenon hull from a small piece of the hull that had survived with a semicircular hole of the same diameter as those found on the Gelidonya that joined together the planks with mortise and tenon joints (Vichos 1999: 77-78).

[1137] Monroe 2000: 360. Lin has analysed from the surviving pieces of the hull and keel and the distribution of the cargo on the sea floor. Using Naval Architecture principles and computer modelling techniques, he has proposed a hull design for the Ulu Burun wreck. A part of the keel survived so that the cross section of keel could be measured. Combining these parameters and knowing the density of the wood the keel was estimated to have a weight of 950 kg (Lin 2003: 62).

[1138] Lin 2003: 32-33.

archaeological evidence for this practice is found on the Gelidonya and Ulu Burun wrecks (Figure 7.9).[1139] Only one small piece of wood from the Point Iria has been recovered and it has a 6mm hole thought to be for a dowel. This is the same diameter as the dowel holes found on the Gelidonya wreck and may suggest a similar hull design.[1140]

Sails improved dramatically in terms of production techniques, design and operation.[1141] Twill differs from traditional weaving by passing the weft thread over one or more warp threads and then under two or more warp threads and so on. The resulting cloth is strongly resistant to tearing and is therefore particularly suitable for the production of sails.[1142] In the same period sails were introduced with the longest edge at the bottom attached and controlled by brails making the ship more controllable in strong winds at sea.[1143] One of the main advances in sailing technology was the development of brailing that enabled ships to sail much closer to the direction of the wind, by changing the shape and size of the sail facing the prevailing wind.[1144] Brails were a series of light ropes attached at intervals of 0.3-0.45m to the bottom of the sail and from there they passed over the yard and down to the stern section. By pulling on different combinations of these ropes the angle and shape of the sail was altered.[1145] The chief benefit of brailing was that it reduced the

[1139] Bass 1961: 270-271; Figure 12, Pulak 1998: 210-213; Pulak 1999: 209-238 and Pulak 2000a: 28-34.
[1140] Vichos 1999: 78-79.
[1141] The organic nature of sails means none have survived from antiquity. Seal iconography and Egyptian tomb paintings give evidence for the designs of Aegean, Syrian, and Egyptian sail designs. Sails were strengthened by ropes and double stitching. Minoan seals depict sails with a form of hatching that could have represented leather strips applied for strengthening sails as attested in the second millennium shipping. Sails were stitched in a way that narrowed the ends so that they could swell with the wind. (Tzachili 1999: 858-859). The introduction of the vertical beam discussed in Chapter 4, Section 4.10.1 enabled long lengths of linen to be woven for larger sails with fewer pieces required. This inherently strengthened the sail by reducing the number of seams.
[1142] Tiboni 2005: 127.
[1143] Baines and Málek 1980: 68-69, Casson 1994: 36 and Vinson 1993: 133-150.
[1144] Geogiou 1991: 66-69, Landels 2000: 155-160 and Roberts 1991: 55-60; plates XVII-XX. It was thought that the depiction of the sea battle between the Egyptians and the "sea peoples" in the 20th Dynasty Medinet Habu relief was the first known example of the use of brails. Vinson 1993: 133-150 shows that there is evidence they were used at least by the Amarna period but were not necessarily designed by the Egyptians.
[1145] Casson 1994: 31-74, Roberts 1991: 55-60, and Vinson 1993: 133-150.

distance sailed between two points by reducing the number of times the ship had to tack against the wind.[1146]

The design of Egypt's seagoing ships did not change significantly throughout the Pharaonic period and was strongly influenced by its river craft tradition which had evolved over several millennia. The design differed greatly from the LBA wrecks; it did not incorporate a keel in the hull design and used ropes to sew the planks together with locating mortise-and-tenon joints.[1147] This minimised longitudinal differential movement of the planks from hogging and bending stresses generated by the combination of cargo and waves; the Egyptians used a hogging truss attached to the stern and bow that could be tightened to minimise the effects of hogging.[1148] If the Palermo Stone is interpreted correctly it indicates that large boats were built by this method as early as the Old Kingdom, as it shows that Snofru built a ship 100 cubits long (170ft).[1149] Their sea worthiness was proven by Sahure of the 5th Dynasty who transported his troops to Syria.[1150] Expeditions to Punt via the Red Sea are recorded from the Old Kingdom to the New Kingdom, the most famous record of all being the texts and wall paintings from Hatshepsut's mortuary temple at Deir el-Bahri.

The improvements in ship design that reduced the risk of sinking together with increased investment in safe harbour facilities contributed in the lowering of maritime costs compared with land transport.[1151] Some work has been carried out by Duncan-Jones on land versus sea transport costs. He analysed Diocletian's Edict on

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[1146] The evidence from first millennium Viking boats with square sails and up to 9 m in length had to tack when the wind was blowing within an area of ± 79° to the direction of travel (called the foul wind sector). The narrower the angle (i.e. the more head-on the wind) the greater distance the boat had to sail through tacking. An angle of ± 34° to the direction of travel would mean a doubling of the distance travelled (McGrail 1983: 299-303). Sailing into the wind and against currents was never fully solved however even by the post medieval period (Pryor 1988: 33-36, 51).

[1147] Casson 1994: Figure 8 shows that this technique is still successfully used today in Madras. Egyptian rope stitch techniques are discussed in Casson 1994: 17-18 and Figure 14, Ward 2000a: 19-23 and Figure 16; Ward 2000b: 53-54 and Ward 2004: 15-24.

[1148] Ward 2000b: 48. As wood is in such short supply this procedure must have developed by using off cuts of wood.

[1149] Recto 6, 3.

[1150] Reliefs in Sahure's mortuary temple at Abusir have been interpreted as Sahure moving his troops to Syria.

[1151] For anchorage systems in use at Tel Nami (Carmel coast in Israel) in the Second Millennium B.C. see Artzy 1995a: 23-30. For overviews of Levantine and Canaanite LBA harbours see Frost 1993: 1-22, Gophna 2002: 418-421, and Raban 1995: 139-190. For Southern Crete see Hadjidaki 2004: 53-62. For Cyprus see Gifford 1985: 45-48 and Raban 1995: 139-190.

maximum prices that shows that a load of grain travelling 100 miles by land was 28 to 1 times more expensive than by sea. As a check he compared the Roman road and sea cost ratios with 18th century A.D. road and sea cost ratios. The result showed a similar land to sea ratio of 22.6 to 1.[1152] The scale of the cost of transport between land and sea was probably similar in the LBA. Ship designs were similar and would have comparable construction costs. Operating costs would be similar as Roman slaves were fed at subsistence level or just above. Differences in trading taxes or harbour dues would not significantly alter the scale of the land/sea ratio.[1153] Both the Romans and the LBA regions used the donkey or oxen as draft animals. If anything the cost of land transport would have been more expensive as the Roman road system was superior to the caravan routes of the LBA.

When the exchange value of all the goods on the Ulu Burun boat is assessed it seems a major risk to put such a valuable cargo on one ship. It is an indicator however that the sponsors of the trading expedition had faith in the robustness of the boat and that it would reach its destination even though events proved otherwise. The value of the cargo and certain design features of the boat suggest that the Ulu Burun boat was not on a tramping expedition but was instead probably a state sponsored high value trading expedition. This boat could have sailed out of sight of the land between major sea hubs. The ships portrayed in the tombs of Iniwia and Kenamun (see ahead Figure 7.23) show that the boats (perhaps of Syrian origin) had lookout platforms (crow nests) attached to the top of the masts.[1154] The visibility from these positions would have helped to overcome the effects of the curvature of the earth, enabling high landmarks to remain in view when travelling along routes normally out of sight from deck level (see again Figure 6.40).[1155] The tides of the Eastern Mediterranean are

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[1152] Duncan-Jones 1974: 366-9.

[1153] See Fitzgerald 1996: 8-9, Pulak 1999: 209-238 and Pulak 2000a: 28-34 for similarities of the mortise and tenon hull construction used in the construction of LBA ships to that of the classical period.

[1154] Wachsmann 1998: 60 gives a warning that the designs of foreign boats portrayed in Egyptian scenes could have been cleverly hybrid constructions rather than accurate representations. Nevertheless even if the crows nest is a figment of the artist's imagination, sailors can clearly be seen on the top yard-arm which they could presumably could climb when the boat was sailing to see in the distance.

[1155] Vella 2004: 42-48.

minimal.[1156] The Ulu Burun wreck was a heavy ship (estimated to weigh in the range 6.5-8.5 tonnes) and with a cargo of 21.1 tonnes on its last voyage, would give a gross tonnage approaching 30 tonnes.[1157] This would make unloading cargoes on beaches a problem as pulling the loaded boat onto the shore would be difficult with the prevailing onshore waves along the Levantine coast. Also the limited height of the tides in the Mediterranean prevented large boats from sailing into the shore on the high tide, and beaching when the tide went out.[1158] It seems more likely then that the Ulu Burun boat used sheltered harbours such as Sidon, Tel Nami, Tyre, and Ugarit which had sufficient depth of water at low tide to enable the boat to float (see again Figures 6.41-6.43).[1159] The estimated draft of the Ulu Burun boat ranged between 1.07-1.29 m depending on the load carried.[1160] This would have restricted the number of places that the boat could unload heavy cargoes. This makes it more likely then that the Ulu Burun boat was used for high value trading missions between sea hubs as discussed below (Figures 7.10-7.11).

It is less clear if the Ulu Burun wreck was an isolated example or one of a fleet of boats circumnavigating Central and Eastern Mediterranean. Examination of the structure of the Gelidonya and Ulu Burun hulls shows commonality of design that was too sophisticated and too similar to have been two independent isolated examples.[1161] The longevity of the mortise and tenon hull through to the Roman

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[1156] The Israeli Oceanographic and Limnological Research centre have plotted the range of the tides off the coast of Israel and the difference between high and low tide is 0.36 m. (Israel Marine Data Center (ISRAMAR). Israel Oceanographic and Limnological Research 2008).

[1157] Lin 2003: 20, note 34, 206, and Table 7.1.

[1158] Marsden 1981: 10-12 and McGrail 1981: 17-23.

[1159] Confirmed evidence of purposely built moles and projecting jetties along the Levantine coast (Tyre and Sidon in particular) are thought to be of Phoenician Iron Age construction (Blackman 1982: 92 and Raban 1995: 145, 153-163). However geo-archaeological evidence of Tyre's ancient Northern Harbour and Sidon's natural harbour show that they were protected from the prevailing south-westerly winds by sandstone reef systems (Marriner *et al* 2005: 1303-1307, 1319 and Figures 2, 14). The geo-archaeological evidence suggest these proto-harbours were in operation in the Middle Bronze Age with Sidon's Northern Harbour dated to 1700-1450 B.C. Both harbours had the facility for small boats to be pulled up on sandy beaches and larger vessels anchored in the deeper water of the bay (Marriner *et al* 2005: 1319 and Figures 15-17). The MBA site of Yavne-Yam, Israel has boulder piles on a submerged ridge suggesting they were placed to improve the quality of the ancient anchorage (Marriner *et al* 2005: 1319). There is evidence that some form of stone quays were built in the sheltered harbour of Tel Dor (Israel) in the latter part of the 14th/early 13th centuries B.C. (Rabin 1995: 148 and Figures 9-10). Raban believes that structures excavated in the harbour level at Kition (Cyprus) resemble the quays found at Tel Dor as well as the ashlar paved basins at Hala Sultan Tekke (Raban 1995: 148 and Figures 14-15).

[1160] Lin 2003: 68.

[1161] Bass 1967a: 48-50 and Pulak 1999: 209-238.

period testifies to the success of its design and makes it more likely that these two boats were part of a much larger infrastructure of skilled boat builders and sailors.[1162] When the improved ship technology is linked to the demand for bronze, the pivotal position of Cyprus in the copper trade, the scale of copper production on Cyprus, and the relatively low-cost of sea transport, it suggests that the Ulu Burun, Gelidonya, and Point Iria wrecks were not isolated high risk trading enterprises.[1163] Instead they should be looked upon as a part of a major maritime trade system regularly connecting all parts of the Eastern Mediterranean and possibly beyond to the Central Mediterranean.

**Networks**

Both the archaeological and textual record show that interregional contact had reached a peak of activity in the Bronze Age during the period 1450 B.C. to 1150 B.C. Improved maritime technology enabled long distance sea routes to be established which not only facilitated movement of goods but may have contributed to the creation of a number of trading blocks.[1164] Each of these trading blocks had a dominant port (that this thesis refers to as a coastal hub) which was linked to others and to local sea or land networks (see again Figure 7.10). Most coastal hubs were also linked to important overland trade routes and some provided gateways from one trading network to another. The harbours on the south west coast of Cyprus may have provided a gateway from the Eastern Mediterranean sea network to the Aegean and Central Mediterranean maritime trading networks.

The locations of the hubs occur at points which optimised transport costs between the regional trading blocks and are found across the Mediterranean (Figure 7.11). The locations of these hubs have been identified from the pottery and oxhide ingot archaeological record using concentrations of these as markers of contact and through this the scale of interregional trade. The oxhide ingots also indicate their provenance from lead isotope testing. Of the pottery, Cypriot white slipware,

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[1162] For an in depth analysis of the Uluburun design see the thesis of Lin 2003. For a discussion of the hull see Fitzgerald 1996: 8-9 and Pulak 1999: 209-238.

[1163] There is another possibly LBA wreck site at Kfar Samir off the Carmel Coast. Copper oxhide and tin ingots have been found but no remains of the boat itself. See again Figure 6.5. For descriptions of the ingots found at wreck site see Galili and Rosen 2007.

[1164] In Section 7.3 below these land and maritime trading blocks will be examined from a 'World Systems' perspective. The 'World Systems' model was developed by Wallerstein 1974a.

Mycenaean pottery, and Canaanite and Cypriot storage jars are the most useful due to their easily recognisable designs (Figures 7.12, 7.14-7.18).[1165] The provenance of pottery fabrics can be determined through chemical and petrological analysis.[1166] Canaanite jars were standardised in design and capacity and this meant they were easier to stack in the boats and easier to monitor quantities loaded and loaded at the ports of call (see again Figure 7.18).[1167] Similarly another indicator of the intensification of trade is the standardisation of the shape of oxhide ingots which represented a weight of metal (23.9 kg) which could be carried by one man.[1168] The shape of the ingot made it ergonomically easier for a man to move the ingot from the ships hull to the dock (see again Figures 7.19).[1169] Similarly glass ingots found on the Ulu Burun wreck appear to have some degree of standardisation as they are of a similar shape to those found in Amarna and Piramesses.[1170]

The probable trade routes are determined using these markers of contact linking them to seasonal sea currents and winds, speed of ancient sailing vessels, known or likely harbour locations (Figure 7.20-7.22). Small boats in the LBA probably kept as much as possible within sight of land for as long as possible (see again Figure 6.40). Larger boats as represented by the Ulu Burun and Gelidonya wrecks probably travelled between the hubs while smaller boats like the Point Iria facilitated local networks.

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[1165] This list of cited works has been chosen to show the wide geographic spread of Cypriot, Mycenaean, and Canaanite pottery encompassing the Central, Eastern Mediterranean and the Northern Coast of Africa. Åström 1991: 149-151, Furumark 1941, Hallager 1993, Hatcher 2007, Leonard 1995: 233-254, Matthäus 2005: 333-366, Merrillees 2001, Mommsen *et al* 1992: 295-302, Mountjoy and Mommsen 2001: 123-155, Pilides 1996: 107-127, Karageorghis 2001: 9-14, Vagnetti 1993, Vagnetti 2001, van Wijngaarden 1999b, Watrous 1985, Smith 1987, and White, Gardner and Hulin 2002.
[1166] The two main methods of chemical analysis are NAA (Neutron Activity Analysis) and ICP-AES (Inductively Coupled Plasma Atomic Emission Spectroscopy). Petrological analysis is a physical study of the clay fabric to determine its provenance by identifying the rocks and minerals making up the clay used to make the pot.
[1167] Grace 1956: 83, Figure 5; Parr 1973: 173-181, and Sherratt and Sherratt 1991: 363.
[1168] See Pulak 2001: 18, Bass 1967c: 52-83 and Buchholz 1959: 1-40 for the standardised shape and weights of copper oxhide ingots. The heaviest ingot weighed 29.5 and the lightest 20.1 kg. The average of the 165 ingots measured was 23.9 kg but some allowance must be made for corrosion (Pulak 2000c: 141). For the 121 smaller plano-convex bun shaped ingots found on the Ulu Burun with an average weight of 6.2 kg see Pulak 2002c: 143-144.
[1169] Sherratt and Sherratt 1991: 363. The most common weight for an oxhide ingot was one talent, approximately 28-29 lbs (Pulak 2001: 18). The shapes did have some variation as identified by Buchholz' typology (Buchholz 1959: 1-40). The provenance of copper ores used to manufacture the ingots will be discussed in chapter 3 section 3.
[1170] Glass ingots did vary in weight but many have a standardised shape of a truncated cone (Nicholson, Jackson and Trott 1997: 143-153). Ceramic moulds from Amarna are of the same size to produce glass ingots as those found on the Ulu Burun wreck. Inside the Amarna moulds traces of cobalt blue glass have been identified (Pulak 2001: 27).

The best sailing season for the Mediterranean known from classical sources was from the end of May to mid September. The worst conditions in the Mediterranean for any maritime activity occur within the period 10th November the 10th March.[1171] Weather conditions vary from year to year but generally it can be concluded that coastal navigation ceased in the winter.[1172] There is no positive evidence of the sailing season in the LBA. Ugarit text RS 17.130 suggests that traders could not stay over the winter time. However as Sauvage points out this could be due to the authorities trying to prevent traders staying too long thus discouraging them from purchasing lands and commodities.[1173]

## 7.2.4 Summary and conclusions for section 7.2

This section has shown that the LBA economy was not minimalist or primitive in nature. The base unit of the food required to feed a nuclear family was used to model the economy of the LBA and this model was based on satisfying the hierarchy of needs. The findings from the model show that Egypt had the strongest economy in the Eastern Mediterranean but even so was subject to harvest failures and periods of prolonged famine several times in every 100 years. Starvation particularly in the case of Cyprus as a result of acute famines could only be avoided with import of grain but some alleviation was possible by reducing rations and the use of a strategic grain buffer stored in granaries filled in the years of glut. The optimum storage capacity for this buffer was found to be 10-15% of the average harvest yield as the cost of labour to build sufficient granaries to store all the food in times of glut would be prohibitive and the surplus was probably exported. This does show however that in years of glut and famine occurring at different times across the Eastern Mediterranean it is likely that a thriving large scale grain trade existed in the LBA. In periods of average harvests 13.3 and 7.3% of the GDP for Egypt and Cyprus respectively could be dedicated to non-basic needs such as state infrastructure projects, added-value

[1171] Casson 1995: 270-271, note 2. In the Classical World the average sailing rates were 4-6 knots but could fall to 2-2.5 knots in adverse conditions. Casson suggested analysing the Roman state grain ships from Alexandria to Crete (a stop off port for supplies) took 11-14 days but on the return journey took 3-4 days (Casson 1995: 287, 201, tables 3-6).
[1172] Tammuz 2005: 145-162.
[1173] Sauvage 2008: 210. Ugarit RS 18.31 states a ship sank in the month of Adaru which corresponds to a period from mid February to mid March possibly suggesting an end date for the winter sailing season (Sauvage 2008: 210).

manufacture of products for export or the conspicuous consumption of the ruling élite (see again Schematic 7.1).

Textual evidence and quantitative case studies have shown that even with the most conservative of assumptions the demand for copper and tin was very high. Indeed comparisons with the cargo on the Ulu Burun wreck shows that this voyage was not an isolated incident but must have been part of a large fleet, possibly based in Ugarit, which sailed around the Mediterranean supplying metals, luxuries, and possible staples to the ruling élites.[1174] The cost of producing copper in the Egyptian mines at Timna was 191% more expensive than in Cyprus (255 man-days/kg for Timna versus 134 man-days/kg for Cyprus).[1175] This would have possibly increased the demand for copper from Cyprus, producing production capacity constraints unless agrarian workers could be taken off the land to work in the mines by a strategy of taking payment in staples for the copper. This analysis compares cost, not prices, as no textual evidence exists for the price of copper produced in Cyprus. The close proximity of Cyprus from Ugarit would suggest that the price of copper in Ugarit would be comparable to that in Cyprus. In Egypt in the fifteenth century B.C. the price of copper relative to silver was in the range 96-104:1 but in Ugarit for the same period the price of copper relatively to silver was expensive in the range 200-235:1.[1176] These ratios highlight the difficulty of comparing prices in antiquity as we do not know the source of the silver in each case and no prices are available for the period 1400-1200 B.C. for this study for Ugarit. It is not possible to correlate the costs derived from BRONZECALC with the relative price levels of Cyprus and Ugarit with Egypt.

The scale, particularly of commodities such as copper, tin, bronze, and blue glass, show that the economy was not 'primitive' based on small *oikos* production units as proposed by Bücher. On the contrary the copper, tin, blue glass, and pistacia resin

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[1174] Wachsmann 1998: 119-125 argues that the identity of the Keftiu ships were in fact Syrian ships based on the textual evidence of ships given as tribute from Southern Syria to Egypt in the Annals of Tuthmosis III, the etymological link between the word *sektu* ships used in the text and the Ugaritic word *ṯny,* and the Syrian ships portrayed in Egyptian tomb paintings that are not traditional Egyptian ship designs an are considered again to be Syrian ships. Two examples are the ships portrayed in the tombs of Iniwia and Kenamun (Figure 6.23).

[1175] The analysis is given in Report 6.1 in BRONZECALC.

[1176] Heltzer 1977: 205.

found on the Ulu Burun wreck, the transport containers found across the Mediterranean that probably contained olive oil, and the industrial complexes such as those at Pylos, Kition, Ugarit, and Piramesses indicate large scale added-value processes were employed to make commodities.[1177] During this period the scale of the production of metals, unguents, perfume production, oils, wool and fine cloth changed from being small, part time cottage industries to production on an 'industrial scale'.[1178] The range of bronze artefacts in the archaeological record show that from a technological perspective the economy had the tools and equipment to increase its productivity across all sectors of the economy and therefore the LBA economy was not primitive in the Bücher sense.

This chapter concludes that the LBA was unique in the Bronze Age not only for the scale of interregional trade but also the variety of goods traded. The measure of interregional trade points to the fact that the economy was not minimal. Cyprus was at the centre of a trading network providing low-cost copper, wood for shipping, and good quality olive oil. The Amarna letters show the King of Cyprus was on equal terms to the other powers in the Eastern Mediterranean. Demand for copper was so high there is a strong possibility that there were copper production capacity constraints in Cyprus. This could explain why Egypt mined Timna copper which was 161% more expensive than Cypriot copper.

Marine archaeological record for this period shows that seagoing ship design had evolved such that investment in fleets of ships rather than singletons made economic sense. Improved design moved shipping from being coast-hugging boats to ocean-going ships capable of transporting large cargoes across open sea. A network of sea hubs and gateways between trading networks facilitated marine transport. It can be concluded that shipping did not provide an inhibitor to the growth in interregional

[1177] For the operation of the metal workshops at Pylos see Lejeune 1961: 409-434.

[1178] I use the term industrial for manufacturing processes carried out on a large scale of which the majority were state owned who paid the workers rations typically of grain. A clear exception was the textile industry in Egypt which because of the demand for fine cloth required in funerary applications was always produced on a large scale. In the Old and Middle Kingdoms however production centred on a large number of small scale production units generally based in the home using a ground loom. Egyptian tomb paintings of two noblemen (Thutnofer TT104 and Neferronpet TT133) may point to the start of a full time textile industry from the 18th Dynasty. Rows of vertical two-beam looms are shown in the basements of noblemen's houses and represent a significant investment (Barber 1991: 113-116, Figures 3.29 and 3.30). See section 3 in chapter 4 for a fuller discussion on textile production.

trade. All of these factors indicate that the economy of the Eastern Mediterranean underpinned by the exchange of the increasing range and scale of goods was not 'minimalist' in the Weber or Finley sense.

This scale of the LBA economy could only have been achieved if a substantial segment of non-agrarian workers in any of the regions under study were supported by the harvest surplus. In a sense the ancient world had shrunk and an early form of globalisation had taken place that would last for 200 years before being destroyed by the Sea Peoples.[1179]

[1179] The role of the Sea People bringing about the transition from the LBA to the Iron Age is covered in Bauer 1998: 149-168, Drews 2000: 161-191, Muhly 1984: 39-56 and Sherratt 1998: 292-313.

# 7.3 A world systems perspective of the LBA Eastern Mediterranean

This section assesses whether the economic dominance of Egypt had on interregional LBA trade in the Eastern Mediterranean from the perspective of Wallerstein's world-systems model. In particular discussion will focus on whether the disparities in economic strength of Egypt distorted interregional trade to an extent that a formalist market could not have functioned.

The size of the added-value workforce plus the state infrastructure workers of Egypt was approximately 15 times larger than Cyprus as demonstrated in the table below.[1180] This was primarily due to its larger population and the size of its harvest surplus.

| | Egypt | Cyprus |
|---|---|---|
| Cloth,shelter/pottery workers + elite | 409,530 | 21,579 |
| Value-add + state infrastructure workers | 293,000 | 10,900 |
| Agrarian workers | 818,510 | 71,235 |
| Total active workers | 1,521,040 | 103,714 |
| Non-productive 55+ & under 6 | 678,920 | 46,290 |
| Total population | 2,199,960 | 150,004 |

**Table 7.10: Summary of the workforce of Egypt compared with Cyprus**

Section 7.2 has clearly shown that the LBA economy for the period 1400-1200 B.C. was not minimalist in nature. On the contrary, the size of the manpower and their dependents that could have been dedicated to added-value production or state infrastructure projects amounted to 20.1% and 11% of the population for Egypt and Cyprus respectively. The cost consolidation in the previous section shows that the Egyptian economy was significantly bigger than the other regions of the Eastern Mediterranean. In a formalist economy this would have given them such a competitive edge that they would have been able to exploit their size and stifle fair trade. The Amarna letters and other texts between ruling élites show that other factors came into play such as gift exchange which placed an obligation on the receiver to give at some point in the future other gifts or grant favours. It is the relationships that were built up through practice of reciprocity that is at odds with the

[1180] For analysis and assumptions see Reports 3.1a-3.1e in AGCALC with appropriate links to spreadsheet models CLOTHCALC, SHELTER, and BRONZECALC.

rational decision of the formalist approach when responding to changes in supply and demand.

The disparity in economic strength of Egypt demonstrated in Section 7.2 compared with the other regions of the Eastern Mediterranean suggests that Wallerstein's world-systems model could be appropriate in determining whether the economic and diplomatic interrelationships between the ruling élites in the Eastern Mediterranean acted in a formalist or substantive manner.[1181] The importance of world-systems model to our understanding of the LBA is that by definition, if a dominant economic core existed, its economy could not be minimalist in scale. Demonstrating that a core exists does not in itself mean that its economy is formalist. It does show however that the *oikos* model is inappropriate. The formalist issue whether market forces governed the economy will be returned to in Section 7.5 below.

This section will examine the evidence to determine whether the LBA regions of the Eastern Mediterranean can be categorised into cores, semi-peripheries, and peripheries. If so did the core dominate and exploit the peripheries for raw materials? If not, was there another economic mechanism operating such as gift exchange which is a substantive characteristic? A brief overview of the world-system model will be followed by an assessment of the relationship of Egypt, Cyprus, and Ugarit from a world-systems perspective. These three regions have been chosen because they played pivotal roles in the operation of the LBA Eastern Mediterranean economy. As stated Egypt was the dominant core economy, Cyprus had three commodities that were universally in demand; copper, wood, and olive oil, and Ugarit with its maritime strength acted as a conduit for tin into the Eastern Mediterranean arena.

Wallerstein's world-systems model postulated that a relationship existed within economic-political networks where the core or cores exploit the periphery states for raw materials and made the latter into dependent satellites. The term 'world' in Wallerstein's model does not mean necessarily mean the whole world but is a definition of an economic-political network where the members of the network must not be transient and where each of them must be of sufficient size they can be

[1181] Wallerstein 1974a

recognised as a unique entity.[1182] Wallerstein's model positions the peripheries as passive recipients under control of the cores political and economic hegemony.[1183] Wallerstein developed the model to explain why some cultures in the modern capitalist world-system gained and continue to have economic and political dominance over the undeveloped third world. Many historians have adapted Wallerstein's theory and applied it the past to attempt to understand the political and economic relationships between ruling élites from antiquity to the past. Wallerstein's approach positions some periphery states as passive recipients under the control of the core's or cores' political and economic hegemony.[1184] Wallerstein defines another category within an economic-political network called a 'semi-periphery' which provided a buffer between the cores and the peripheries. Semi-periphery states may have been former cores that had fallen on hard times or a periphery that had developed through new found natural resources or technological expertise became semi-peripheries.[1185] Within a world-system some of the peripheries or semi-peripheries could have been under the hegemony of a particular core but this does not have to be the case.[1186] The trading patterns of the LBA suggest that two other world-systems bordered the Eastern Mediterranean (Figure 7.24). The Central Mediterranean extending from Sardinia in the West to Crete in the East and encompassing Mainland Greece, Italy and the Adriatic to the North and another to the East that included Mesopotamia and Central Asia.[1187]

## The role of the cores in the LBA

The analysis of scale of the LBA economy in Section 7.2 clearly demonstrates Egypt's economic dominance in the Eastern Mediterranean making it an obvious

[1182] The model has been used extensively by historians to analyse ancient cultures large and small. Two of the best reviews of the issues and the application of the world-system model to study of the past are Chase-Dunn and Hall 1997 and Rowlands 1987: 1-12. Renfrew is probably the most sceptical; questioning the validity of using the term 'world' in 'world-system' when applied to prehistoric cultures. He questions how many cores and peripheries have to be within an exchange network before trade moves from a small, local trading system into a world-system. He concedes one benefit of the model "...it brings up for consideration the question as to whether various regions are so highly coupled together in their trading networks that their economies can no longer be considered separately, but should rather be considered as a single functioning whole" (Renfrew 1993: 7).
[1183] Kardulias 2007: 1.
[1184] Kardulias 2007: 1.
[1185] Wallerstein 1974a: 41.
[1186] Schortman and Urban 1992: 17 citing Wallerstein 1974a: 348 and Wallerstein 1979b: 156.
[1187] Edens 1992/1993: 118-139.

core. The cores had the benefit of maximising wealth as they had the flexibility to choose and to optimise the location of production sites to maximise return on effort expended.[1188] Egypt was in this fortunate position as it could procure copper from the Egyptian controlled mines at Timna in the Sinai, within its own boundaries in the Eastern Desert, or import copper commercially or through gift exchange as demonstrated by the Amarna Letters.[1189] The Kingdoms of Hatti (Hittites) and the Mitanni, though cores in their own right, would have been subservient to Egypt in economic but not necessarily military or political terms.[1190]

The economic power of the Pharaonic Egypt in the Eighteenth and early Nineteenth Dynasties was at its peak. It had successfully exploited mineral resources to the north and south of its borders which enabled it to accumulate vast wealth. The annual inundation ensured that in most years a harvest surplus was the norm and could be exchanged for imported goods. As important to the growth in trade was the greater awareness of the material culture, food and customs of other regions gained through the diplomats who had been appointed to maintain Egypt's imperial interests in the Near East and Nubia. This awareness increased the demand of the Egyptian élite for exotic goods through exchange or tribute. Egypt's new outward looking posture not only changed its own internal economic priorities for foreign goods in terms of size and diversity but as a consequence of the demands created it had the effect of stimulating the economies of the other regions.

The Hittite culture had great economic wealth based on rich farming land on the central high plateau of Anatolia. With adequate rainfall in the spring growing season, harvests were large. Central Anatolia also had dense forests that could be harvested for timber. The Anatolian plateau provided rich metal resources of copper, iron, and

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[1188] Rowlands 1987: 5.

[1189] The Egyptians also had gold mines in the Eastern Desert stretching from Qena-Qusier to the current Sudanese border (Ogden 2000: 161). The bulk of Egyptian silver was in fact a natural alloy of silver and gold (Gale and Stos Gale 1981: 103-115). The benefits of having resources of gold and silver to the economy, particularly interregional trade will be returned to in Section 7.5.2 below.

[1190] The Hittites and the Mitanni were strong military powers. The hegemony of Egypt over Ugarit was lost in the Amarna period when it was integrated into the Hittite empire ca. 1365 B.C However from this point until the end of the LBA to the Sea Peoples in ca. 1200 B.C. Ugarit provided a buffer zone between the Egypt and the Hittites. As the power of Mitanni waned the Ugarit buffer helped protect the Eastern Mediterranean flank from the rising power of Assyria in the East (see again Figure 1.2). It was this balance of power and relative peace that led to 200 years of expanding interregional trade between the Central, Eastern and Mesopotamian world-systems.

tin, gold, silver. Although landlocked it did have access to foreign goods through the ports of Ura on the coast of Cilicia, and Ugarit.[1191] Trading links extended from Troy, through the Black Sea via the Danube to Central and Eastern Europe.[1192]

The Mesopotamian culture had two major rivers the Euphrates and the Tigris. This enabled its agriculture to produce a surplus, which could be used to support industries to produce goods for export. The rivers were similar to the Nile in that they provided efficient methods of transport of goods and people and connected directly and indirectly with the caravan routes from Afghanistan and farther east. These caravans brought tin into Ugarit for transhipment by sea to all parts of the central and eastern Mediterranean. Another major export was lapis lazuli one of the precious stones required for the luxury market.

During the same period the Mycenaean influence was spreading, their pottery in particular is found throughout the Mediterranean (see again Figure 7.12). After the destruction of the Mycenaean palaces in mainland Greece their culture continued, either by migration or enforced colonization, to spread across the Eastern Mediterranean. Knossos, Mallia, Phaistos and Chania became centres of Mycenaean control in the LM II to LM IIIA periods (1450-1375 B.C.).[1193] The extensive legacy of Mycenaean pottery in Cyprus and the Levant, much locally produced, indicates that skilled craftsmen had probably established themselves, if not as colonists then at

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[1191] The site of the port of Ura has not been conclusively identified. Beal 1992: 65-73 proposes Ura as being on the Cilcilian coast of Cilcili perhaps close to modern Gilindere. Albright 1961: 44 n. 42 and Lemaire and Lozachmeur 1987: 373-377 suggest Ura's location is close to the modern port of Silifke (classical Seleucia).

[1192] Hiller 1991: 207-215, plate LVIII suggests that Troy was an outlet for both Anatolian and Mycenaean goods. Troy was not therefore a terminal point for Aegean traffic but an intermediary port for Mycenaean ships on the way to the Black Sea and beyond. Aegean copper oxhide ingots, pottery, stone anchors, weapons have been found across 13 Black Sea settlements. Some may be contemporary imitations but even so still indicate a familiarity with Aegean goods and possible direct contact. Sherratt and Sherratt 1998: 337 put forward the case that the route to Italy across the Alps subsequently became the route of choice for trade into Central Europe from the Aegean and the Central Mediterranean.

[1193] Popham 1994: 94-98, plates 6 and 7. Popham draws evidence for Mycenaean influence from the evidence of the Linear B tablets at Knossos, the military symbolism of the figure-of-eight shield, Mycenaean boar tusk helmets, sword and dagger, and changes in tomb design and burial practices. With the final destruction of Knossos ca. 1375 B.C., linear B script is not found on the Island, suggesting an end to any form of centralised or regional palatial control some time after this date. Rehak and Younger 1998: 99, table 1; 149-152 suggest a date for the end of any form of palatial administration/influence as early LM IIIB (ca. 1320 B.C.). Deger-Jalkotzy 2006: 165-167 suggests that three warrior tombs in eastern Crete at Mouliana, Praisos-Foutoula and Myrsini were LM IIIC that would give a Mycenaean end date possibly as late as 1220-1100 B.C.

least as accepted refugee craftsmen. Gill, though referring to the Classical period, reminds us that traded pots found in the archaeological record do not necessarily indicate migration of peoples or craftsmen:

> It is noteworthy that the Phoenicians are re-emerging in modern scholarship as the carriers of Greek pottery ...........the appearance of non-Greeks in the literary sources as the carriers of pottery should encourage us to rethink the view that the spread of Greek artefacts indeed represents the spread of the Greeks overseas.[1194]

The Central Mediterranean held a key role providing an interface between the markets of the Eastern Mediterranean and those of Western and Northern Europe. Italy provided a conduit across the alpine passes for Western European trade in general and amber in particular.[1195] Italy and Sicily developed expertise in high quality weapons that were in demand from the north, west and east. Sardinia provided a gateway for trade between the Western Mediterranean and the Eastern Mediterranean.

## The role of the semi-peripheries in the LBA

The case whether Cyprus was a periphery or semi-periphery is less clear than for Egypt. Peripheral élites had less flexibility to choose trading partners, as they could be forced to trade with the core by military and/or economic forces.[1196] The vassal Southern Levantine states and Nubia fall into this category as they were under the hegemony of Egypt, while varying parts of the Levant were under the hegemony at different times between Egypt, the Hittites, and the Mitanni. Cyprus was an island with safe harbours on the West and South-west coast and was well positioned to take part in trading activities being only 72 km from Ugarit (Figure 7.25). The prevailing winds for seven months of the year and currents made Cyprus an ideal interface between the Central and Eastern Mediterranean world-systems (see again Figures 7.21-7.22). At the same time it was sufficiently remote from the mainland to be isolated from the political and military posturing between the three super-powers Egypt, the Hittites, and the Mitanni. The capacity of these land based powers to send a task force to invade the island was limited for this period. It is this insularity which

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[1194] Gill 1994: 107.
[1195] Bachhuber 2006: 332, footnote 90. Amber was popular in the Aegean but rare in the Eastern Mediterranean. In Cyprus only six beads have been excavated from Enkomi, two beads from Aššur in Mesopotamia and 17 scarabs from 18th Dynasty Egypt.
[1196] Wallerstein 1974a: 349.

enabled it to maintain its neutrality but at the same time exploit its commercial maritime connectivity that made Cyprus so important in interregional trade of the period.[1197] For these reasons Cyprus may not have been a periphery but more suitably described as a semi-periphery as defined by Wallerstein.[1198] The archaeological record on Cyprus shows that conspicuous consumption in both tomb goods and monumental ashlar buildings increased significantly in the transition between the LBA and EIA (1250-1150 B.C.) indicating that the economy had grown to the status of a semi-periphery with the potential to grow into a core.[1199] This increase is important because from a world systems perspective Cyprus was becoming a counter balance to the economic dominance of Egypt and therefore changing the interrelationship of the Eastern Mediterranean states. The events of the widespread destruction by the Sea Peoples in the first part the Twelfth Century B.C., that created an Eastern Mediterranean wide economic depression, curtailed any progress of Cyprus to become a core in its own right.

Ugarit may also have been a semi-periphery as it held a unique, strategic, geographic and political position in the Eastern Mediterranean. After its hegemony passed from Egypt to the Hittites ca. 1365 B.C. Ugarit provided a semi-autonomous buffer zone between the two states Egypt and the Hittites.[1200] For most of the period the Eastern Mediterranean was relatively peaceful and stable, encouraging the ruling élite to invest in trading enterprises. Although Ugarit was under the hegemony of the Hittites, Ugarit provided a strategic political buffer between the rival powers of the

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[1197] Knapp 2008: 24.
[1198] See contrary view that Cyprus remained a periphery (Manning and de Mita 1997: 110-111).
[1199] Keswani 2004.
[1200] Although Ugarit was under the hegemony of the Hittites, texts show that the Kings of Ugarit had a high degree of autonomy particularly at the close of the 13th Century B.C. An edict of Ŝuppiluliumaš later confirmed by Murŝiliŝ, increased Ugarit's kingdom by ca. 2225 sq. km compared with its original territory of ca. 3225 sq. km, mainly at the expense of the vanquished Mukiŝ. The newly acquired land comprised valuable forests (1000 sq. km) with the rest of the land being rich farmland (Astour 1981: 21). Initially Ugarit was under the power of Egypt but there is a degree of uncertainty exactly when this happened. Ugarit was definitely an Egyptian vassal state during the reign of Amenhotep III (1391-1353 B.C.) possibly as early as the reign of Tuthmosis IV (1401-1391). Despite an alliance with the Mitanni ca. 1400 B.C. Egypt had lost its hegemony over Ugarit by the Amarna period when Ugarit was integrated into the Hittite empire ca. 1365 B.C. Tablets PRU IV 1 and PRU IV 2 describe how Niqmaddu, the king of Ugarit changed allegiances from the Egyptians to the Hittites after Ŝuppiluliumaŝ, the Hittite king had agreed that any captured border towns and prisoners of war could be retained by Ugarit (Astour 1981: 20). Egypt and the Hittites had agreed to a peaceful coexistence signing a peace treaty between Ramesses II and Hattušiliš III in the formers regnal year 21.

Hittites, Egypt, and the Mitanni and the rising power of the Assyrians to the east (see again Figure 1.2). Capitalising on the relative peace of the period and its geographic position Ugarit became a focus of trade by becoming the main conduit of tin and other commodities into the wider Mediterranean arena (see again Figures 6.41-6.44). Economic texts show that tin as well as copper was traded within the kingdom.[1201] The texts also indicate the wide range of other goods that were imported and exported into the port of Minet el-Beida (Mahadou) for internal consumption by the citizens of Ugarit.[1202] Ugarit's wealth was not limited to maritime trade as known from textual sources for the lucrative 'caravan' trade with the Anatolian and Mesopotamian markets.[1203] They show that at Hattusha a 'commercial bank' had been established with considerable capital to finance Ugarit-Hittite trade.[1204] Ugarit also commanded the caravan route from the coast, through the Amuq plain to Aleppo, which connected to the caravan route to Carchemish via Emar.[1205]

Ugarit's large merchant fleet was capable of travelling to any part of the central and eastern Mediterranean. As stated above Ugarit had well protected harbours and was centred on the intersection of two major caravan routes. The importance of sea transport to Ugarit is demonstrated by the fact that its western Semitic language had 28 words for ship. Of the 28 words the most common was *ʿanyt*.[1206] It had a fertile hinterland protected to the east by high ground. Ancient caravan routes connected Ugarit with the lucrative tin trade in Central Asia and a north-south route connected Hatti with the rest of the Levant. Its east-west route, carrying tin, gave it a considerable trading advantage over other ports along the Levantine coast.[1207] Texts

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[1201] Tin is mentioned in six texts from Ugarit (Heltzer 1977: 203). Also see Linder 1981: 37 for textual evidence of requests for imports of copper by sea.

[1202] Yon 1994: 421-427 Ugarit in the LBA had maritime trading relationships with Byblos, Tyre, and Akko (Heltzer 1977: 209 with full textual references).

[1203] Nougayrol 1956, PRU VI 14 (Astour 1981: 22, footnote 105). For the caravan routes see Drower 1975: 131, Astour 1995: 1415 and Woolley 1953: 20. A major caravan route ran north to central Anatolia taking advantage of north-south alignment of the Syrian mountains and principal rivers. It crossed the Orontes at the site of Antioch, bypassing the eastern side of Mount Casius, over the Beilān pass in south-east turkey before traversing Taurus Mountains using the Old Assyrian caravan route through the Eyerbel Pass.

[1204] Nougayrol 1956, PRU IV 53: 17-19; PRU IV 22 (Astour 1981: 22, footnote 106).

[1205] Drower 1975: 131. At Carchemish trade moved up and down the Euphrates to Babylon or by another caravan route eastwards to Assyria through the Upper Khabur region.

[1206] Thereau-Dangin 1981: 228-230.

[1207] Ugarit had its main harbour, Mahadou, 1.5 km. from Ras Shamra and a number of smaller harbours north and south (Astour 1970: 113f , Heltzer 1976: 21-24; Heltzer 1982: 188-191). One of these, Rašu, was close to Ras Shamra (Soldt 2005: 142-144).

and artefacts found in the harbour warehouses indicate that a wide range of imports and exports passed through Ugarit.[1208]

In summary, from a world-systems perspective, both Cyprus and Ugarit were semi-peripheries. The natural resources of Cyprus and its geographic position that gave it connectivity to the Central and Eastern Mediterranean trading systems as well as security enabled it to have an economic influence considerably above what would be expected from the size of its population. By the end of the LBA, Ugarit fulfilled Wallerstein's criteria for semi-peripheries, being wealthy from trade by land and sea. It was not a core because it was still under the hegemony of the Hittites, its absolute population was small, and its agricultural sector would not have delivered a significant harvest surplus.

[1208] Texts show male and female slaves, horses, fabrics, textiles and oil were imported (Yon 1994: 421-427). Numerous container pots for oil and grain have been excavated in Ras Shamra and in the warehouses at Minet el-Beida (Yon 2006: 142-143).

# 7.4 Evidence for cost accounting in the LBA

This section will examine the accounting systems used by Egypt, as a representative of other regions in the LBA, to determine if they were able to plan complex projects in terms of cost, monitor the cost projection against actual costs, and take action to ensure the objective was realised.[1209] If these processes were in place then it would counter the objection made those who take a primitivist view of the economy that growth in the ancient economy was limited due to the lack of a proper cost accounting process.

Egyptian texts show that economic accounts reflect five main dimensions: the physical organization of labour and assigning tasks, monitoring and control of workers' attendance, determining work targets, reporting on tasks performed, and calculating and distributing wages.[1210]

## 7.4.1 Determining work targets

This section examines Egyptian cost accounting processes to determine whether they went beyond the arithmetic assessment of workers' attendance or stock levels to see if they had within them characteristics that are in common with modern management cost control practices. These practices involve setting objectives, planning, forecasting, and measurement of plan versus actual achievement. Simpson's analysis of work activities recorded in the *Reisner I* and *Reisner III* papyri shows that not only were labour requirements planned for the initiation of a project, the Ancient Egyptians also forecasted projected manpower requirements, using man-day ratios. These rates reflected a wide range of activities and showed the sophistication of their

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[1209] Egypt has been chosen because of the wealth of textual evidence available. Egypt was representative of the other large redistribution economies of the Eastern Mediterranean and Mesopotamia. Cyprus is silent from a textual perspective on its administration processes but the archaeological record shows that the Cypro-Minoan script found on the oxhide ingots and other items, and seals and nodules found in the Cypriot harbour towns that they too had developed processes that could track items for trade and internal administration (Daniel 1961: 249-282, Hirschfield 1993: 311-318, Knapp 1983: 38-45, Landau and Goren 2004: 22-31, and Palaima 1997: 121-187). For markings on oxhide ingots on the Uluburun see Pulak 2000c: 146, Figure 13, and for markings on Cypriot oxhide ingots found in Sardinia see Lo Schiavo 2005: 407-408, Abb. 9).

[1210] Ezzamel 2004: 498.

control processes.[1211] *P. Reisner I* demonstrates how the scribes used conversion factors to calculate the man-days required to move different materials starting for a given volume of material.[1212] The conversion ratios of man-days to volume of material moved were in Section K of *P. Reisner I* for following activities. These ratios were: 1:10 for rubble and earth, 2:9 for builder's materials (not specified), 5:1 hauling stone, 2:3 for sand movement, 1:65 for moving mud bricks, and 1:10 for loosening earth.[1213] The work of Kadish has shown that the administration used the concept of man-day rates to determine the manpower requirements and materials for a wide range of construction projects.[1214] With the benefits gained from the use of manpower rates in accounting practices it would be surprising if the administration did not apply manpower and materials planning to all forms of non-basic state investment activity. Knowing the man-days required for any project gave the administration the basic information needed to calculate the rations required to support the workmen and this will be covered next. The same data complemented by the size of the harvest surplus together with the grain stored in the state granaries enabled investment decisions for state projects to be made on the basis of affordability.

## 7.4.2 Calculating ration requirements for workers

This section will demonstrate that the Egyptian administration had accounting algorithms that enabled them to plan for and redistribute rations which took into account different wage structures based on rank and profession. Mueller's analysis of the wage rates in the Hammamat texts show that the basic rations for a common manual worker were a single ration of ten bread loaves and ⅓ unit of beer, a "hunter"

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[1211] The Egyptians man-day was based on a ten hour working day (Simpson 1969: 14 citing Neugebauer and Parker 1960: 118). Even as early as Dynasty VI in the Old Kingdom the term man-day was used to plan state projects (Berlev 1965: 264).

[1212] Simpson 1969: 13-14.

[1213] Simpson 1969: 15. This was used in Reisner II to calculate the man-days to move the sand and stone used in one operation in the construction of the royal dockyard project in the reign of Sesostris I which amounted to 101½ to move the sand and 715 man-days to move the stone (Kadish 1996: 443 citing Simpson 1965: 32-33).

[1214] A man-day rate is defined as the number of days to complete a specific task. Using this rate the total manpower requirement for a specific task in the project would equal man-day rate times the number of times the task was required to complete the project. In projects the complexity of building the pyramids this could amount to numerous man-day rates. Kadish's analysis of Simpson's work on the Reisner papyri (Simpson 1963, Simpson 1965, and Simpson 1969, and Simpson 1986) has shown that workload planning went far beyond just the movement of materials (Kadish 1996: 439-449).

received 1.5 ration units of 15 bread loaves and ½ units of beer, and a craftsman received a double ration of 20 loaves and ½ unit of beer.[1215] Similarly in the New Kingdom 19th Dynasty a manual crew member working from the Workmen's Village at Deir el-Medina received rations paid in emmer wheat and barley. Hereafter the term 'crew' will be used to refer to these organisational units which typically made up of foremen, skilled workers, guards, and porters. Skilled manual workers at the royal necropolis received an annual wage of 48 khar of emmer wheat with an additional 16 khar of barley. The chief workman received 66 khar of emmer wheat with an additional 22 khar of barley. For a guard the emmer ration was 24 khar of emmer wheat and 8 khar of barley and for a porter as low as 12 khar of emmer wheat and 4 khar of barley.[1216] In addition they received rations of fish, firewood, garments, water and unspecified quantities of vegetables.[1217] To maintain a healthy lifestyle a minimum 1,091 kg of grain per annum per family was required.[1218] The porter with an annual grain ration of 896 kg was therefore 195 kg below the subsistence level and he and his family would have to find additional work to meet the basic nutritional needs of his family. Conversely the chief workman (foreman) with a ration of 4,927 kg would have a surplus of 3,836 kg/annum which he could have bartered in the local markets.[1219] We shall return to this topic of surplus grain for state workers in Section 7.5.1 below when discussing the implications to the economy of surplus grain outside of the control of the state administration.

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[1215] Mueller 1975: 253. This text is from the reign of King Sesostris I.

[1216] Janssen 1975a: 460-466. For modern equivalents converting khar rations to volume litres and dry weights kg using conversions factors of 1 khar = 76.8 litres and the dry density of barley and emmer wheat is 609 and 769 kg/m$^3$ respectively give the following for emmer wheat: 66 khar = 5,070 litres/3,900 kg, 48 khar = 3,690 litres/2,840 kg, 24 khar = 1,845 litres/1420 kg, and 12 khar = 920 litres/ 710 kg. For barley the modern equivalents are: 22 khar = 1,690 litres/1,030 kg, 16 khar = 1,230 litres, 750 kg, 8 khar = 615 litres/ 375 kg, and 4 khar = 307 litres, 187 kg.

[1217] The fish ration in the reign of Ramesses III was 8.4 kg of fish per month (McDowell 1999: 232). Occasionally the gang working on the royal tomb received luxuries as attested by stele British Museum 588, translated by Janssen 1963: 64-70. They included fine cloth, bronze *kebu*-jars, silver *tjebu*-vases, sweet *ben*-oil, honey, fat, cream, incense, olives, papyrus, and olives. For a complete list see McDowell 1999: 234.

[1218] On top of the grain it is assumed that the diet for a family per annum is supplemented with 766 kg of pulses, 64 kg of dairy/oils etc, and 142 kg of fish and meat per year. The protein allowance assumes that 102 kg/family/year was fish caught in the Nile (Janssen 1961: 18). For details of the analysis and assumptions relating to LBA diets see Reports 3.4-3.5 and 3.20-3.21 in AGCALC and Section 3.2 in Chapter 3.

[1219] The evidence suggests that most local market places were located near the Nile riverbank (Eyre 1987a: 31-32 and Kemp 1991: 254-255 and particularly the bartering scenes (Figure 86) at the riverside as illustrated in the tomb paintings of Kenamun and Ipy). In lower Mesopotamia similar markets were situated on river quays that were named kārum in Old Babylonian texts (Leemans 1960: 1, footnote 1).

Another example which shows planning ration requirements was calculated using rank rather than using the headcount can be found in the Rhind mathematical papyrus. This was written to train and assist scribes how to allocate resources. Problem 65 of the text asks the scribes to distribute 100 loaves between ten men on single rations, and a sailor, a foreman, and the doorkeeper on double rations. The solution given was to divide the hundred loaves into 13 portions using the Egyptian system of multiplication and division by remainders with a single ration of 7 + 9/13 for the manual workers and 15 + 5/13 for the officials.[1220] The use and clarity of the ration accounting process would have given the administration two main benefits; it would have minimised corruption as the whole process was tracked by scribes from forecasting demand to the issuing of loaves and beer as rations, it also gave the administrators working on the project early warning that additional rations would be needed to complete the task if the project was falling behind time. The whole process was made easier because in Egypt standard size loaves and a standard unit of beer each made to the same recipe, ensured that each man's ration for any given rank or profession was the same as the next.[1221]

## Summary

Weber argued that the concept of cost accounting did not exist in antiquity as there was no method of apportioning costs.[1222] This section has clearly demonstrated that the Egyptians had a sophisticated method of cost accounting that gave them the means to calculate the effort in man-days needed to produce products and provide services. The cost accounting processes in Egypt were used extensively and provided the administration with information to plan, control, and forecast and manage large scale projects and the logistics of an extensive redistribution system. The wide range of textual evidence for the use of these processes counters the substantive view that the ancients did not have cost accounting processes of sufficient sophistication to enable the ancient economy to reach its full potential. What is not proven is that these cost accounting processes replicated the accounting processes in modern

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[1220] The stages of the calculation are given in Robins and Shute 1987: 16 and 42.

[1221] Using the same recipe to make a loaf or a unit of beer ensured rations had a consistent uniform size or volume that gave the same nutritional content to the consumer. This was referred to by the Egyptians as *Pefsu* meaning 'baking value'. Bleiberg 2007: 182.

[1222] Discussed earlier in Section 1.1.

formalist economies. Firstly none of the textual evidence indicates they were used to ensure that the projects were planned so that they would achieve a return on investment. Secondly the focus of Egyptian cost accounting was in fact process control that ensured food and material arrived at the right place and the right time to complete the project. Cost accounting was not used as in modern practice, to monitor and control costs to ensure that ongoing costs met the planned costs, or managed recovery to plan. In summary it is the motivation for cost accounting that was different in antiquity.

# 7.5 The scale of rations in the informal economy

It has been shown above that rations paid to New Kingdom skilled state workers varied by their rank and profession and they were allocated more rations than they needed to feed themselves and their families. It is the quantification of these surplus rations (hereafter called informal economy) circulating outside of the control of the administration that could have stimulated an embryonic formalist market.[1223] The term informal economy has been used to differentiate it from the state and temple economies; this informal economy was outside the state and temple taxation processes. Effective long term storage of grain beyond the current harvest by private individuals was limited making the surplus grain prone to wastage from pests. It can be seen from the table below that a skilled worker would require 3.2 $m^3$ of grain storage on top of that required to feed the family for a year 1.5 $m^3$.[1224] This would probably be above the storage capacity of most houses in Deir el Medina with an average usable footprint of 40 $m^2$.[1225]

| Rank within crew | Volume (litres) of surplus grain for Deir el-Medina | Volume ($m^3$) of surplus grain for Deir el-Medina |
|---|---|---|
| Chief foreman | 4,988 | 5.0 |
| Skilled worker | 3,241 | 3.2 |
| Guard | 910 | 0.9 |
| Porter | N/A no surplus | N/A no surplus |

**Table 7.11: Volume of surplus grain over that required to meet the calorie requirements to feed an average family**

A possible outcome would have been to barter the surplus in the local market. It is not surprising therefore that the Deir el-Medina texts show that the workers used grain to accumulate luxury goods.[1226] This would also have been the case for the agrarian sector of the Egyptian economy in times of glut when they would have had

[1223] This quantity of grain may be understated as Cooney presents a convincing case that there is sufficient textual evidence to conclude there were independent craftsmen building and decorating private tombs on the West Bank at Thebes. They worked independently or semi-independently of the state and became wealthy in the process (Cooney 2007a: 171-173).
[1224] The full analysis and assumptions are given in Reports 3.21f-3.21L in AGCALC.
[1225] Usable space is defined as the area inside of the walls which can be up to 1 m thick at Deir el Medina.
[1226] Cooney 2007b: 79-115.

at their disposal a grain surplus over and above the tax to the state (or rent to the temples if working on temple estates).[1227]

Many state workers were paid in loaves and beer rather than grain as was the case for the Deir el-Medina workers and a proportion of the bread and beer rations probably entered the informal market. Unlike modern breads and bears that use sulphur dioxide in the production process to kill unwanted bacteria and preservatives for a long shelf life, bread and beer in antiquity could not be stored for any lengthy period. In the New Kingdom textual and archaeological evidence shows that state bakeries produced large quantities of baked loaves of bread and fermented beer which was distributed to workers on state projects.[1228] Rations were again paid according to rank and profession. The lowest paid workers received ten loaves of bread and two full jugs of beer per day.[1229] Higher ranked workers such as a captain of a boat received 38½ loaves but the most junior crew member received only 1½ loaves.[1230] The priests were more affluent because in addition to their standard allocation of food rations they receive a commission on the tax and rental dues paid to the temple from tenant farmers.[1231] The fact that some people received rations in excess of their needs which could not be stored means that there is a strong likelihood that a significant proportion of these surplus rations would have entered the informal economy.

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[1227] Janssen 1979: 511. The Wilbour Papyrus shows that the tax rate was 1.5 khar/aroura or (Katary 1999: 65).

[1228] For an extensive coverage of the Egyptian baking and brewing processes see Samuel 2000: 537-576 with full references for the archaeological, textual, tomb models, tomb paintings, and experimental archaeology evidence.

[1229] Bleiberg 2007: 182. An inscription in the 6th regnal year of Seti I shows that the rations for royal workers did vary in the New Kingdom. Quarry workers at Silisa, on the East Bank opposite Kom Ombo, received 4 lbs of bread daily. In addition they received 2 sacks of grain, a portion of roast meat and a bundle of vegetables each month. The Kings Messenger responsible for the quarrying received daily: best bread, beef, wine, pomegranate-wine, oils, honey, figs, grapes, fish, and vegetables (Kitchen 1982: 26).

[1230] Bleiberg 1995: 1380.

[1231] For example in the Middle Kingdom temple of Wepwawet received a commission on the taxed goods arriving to fill up the temple granaries as well other tax goods received in kind. The commission reflected rank. Taking the case of the grain tax receipts; high priests received the 2/360th of the grain received that day and the regular priest received 2/360th of the daily quantity arriving at the temple. The unit of reckoning equated to one temple day (Kemp 1991: 126). Hieratic papyri from Kahun show that priests received a specified fraction according to rank of the meat received at the temple as tax in kind (Griffith 1898: 45-46, Plates XVI, XVII). We do not have direct textual evidence for this practice in the New Kingdom but it was probable that this practice continued.

## 7.5.1 The impact on the LBA economy of surplus rations

Surplus grain entering the informal economy could have impacted the demand for goods normally associated with the élite. Although textual evidence indicates there was widespread if not universal distribution of food rations to non-basic state workers it is reasonable to assume that there would be a demand for additional grain in local markets because family sizes varied considerably in antiquity as discussed in Chapter 3. Cooney proposes the workforce can be divided into three main categories: unattached labour systems (craftsmen in rural villages), fully attached state labour systems (workers employed on state infrastructure, expeditions, and royal/temple building projects), and semi-attached labour systems (private businessmen or part time craftsmen as attested in Deir el-Medina). This case study will concentrate on the second and third categories as the evidence relating to rural craftsmen is very limited. However these unattached craftsmen within the rural community, who gained their income from the agrarian sector, would probably like their state counterparts, have been paid for their services with food and oil. The net result is that all three categories would have contributed to the size of the informal market.[1232] In addition the lowest paid state workers, as represented by the porters working on the construction of the royal necropolis at Deir el-Medina, were near or below the subsistence level. To supplement their rations they could have worked part time in cottage industries producing the goods that would be exchanged for grain in the market place.[1233]

This case study attempts to estimate the scale of this flow of surplus rations entering the 'informal economy' that was used for bartering and centred in local market

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[1232] Cooney 2007a: 160-174.

[1233] The evidence that the workers at Deir el-Medina were not on basic subsistence level of rations is shown by the fact that the more affluent could afford goods made by other craftsmen. This is known from a wide range of ostraca that were probably typical of most villages throughout Egypt. Three examples amongst many illustrate this diverse informal market: the payment of 1½ sacks of grain for construction work in the house of Paneb, tomb decoration provided by A'o-nakhte to Mery-Sekhmet for a range of goods including sandals, grain, 6½ silver units, and the production of a headrest for Qen-her-khepish-ef's tomb (McDowell 1999: 66-69, 71). For a review of selected texts of more mundane services such as shopping for food, clothes, building repairs and general carpentry see again McDowell 1999:73-85. For an extensive review of a thriving business that rented out donkeys see Janssen 2005.

places.[1234] The emphasis of the case study is to estimate the scale and not the absolute quantity of rations entering the informal market. The quantity of rations entering the informal market is a function of three variables: the absolute number of state workers; the number of foremen, skilled workers, guards, and porters that worked in the crew, and the quantity of rations distributed per worker according to his hierarchical rank within the crew. The amount of food surplus entering the informal economy approximates to the following algorithm:

Number of foreman × (foreman's rations – food required to maintain healthy lifestyle plus their families) + Number of skilled workers × (skilled workers rations – food required to maintain healthy lifestyle plus their families) + Number of guards × (guard's rations – food required to maintain healthy lifestyle plus their families) + Number of portes × (porter's rations – food required to maintain healthy lifestyle plus their families). As the number of the non-basic workers as well as their exact organisational structure of crews is unknown the following assumptions are made:

## Assumption 1

The upper limit of the work force which could be supported in state infrastructure projects or added-value activities was 293,000 workers.[1235] It is not known for certain how many of these workers received full state rations so four cohorts of state manual workers been chosen up to this upper limit: 50,000, 100,000, 200,000, and 300,000 men.

## Assumption 2

As early as the Old Kingdom manual state workers were organised into crews the size of which varied considerably over time and the work undertaken.[1236] We know

[1234] For convenience this case study uses the Deir el Medina grain rations rather than bread and beer rations though the Reisner papyri evidence indicates that the respective ration levels were comparable.
[1235] See Reports 3.1a-3.1b and 3.1e in AGCALC for assumptions and analysis. Report 3.21a in AGCALC shows that the non-basic workforce was 14,152/100,000 population, so with a population of 2.2 million the upper limit of state workers would be = 14,152 x 22 = 311,300 equating to 28% of the male population of 1,100,000 for the New Kingdom. It is assumed that the physical nature of the work involved in state mining, bronze making, and monumental building construction among many examples precludes the use of women. As noted this thesis has assumed an Egyptian population of 2.2 million for the end of the New Kingdom.
[1236] Eyre 1987a: 12. In the Old Kingdom a crew could have up to 400 men made up of two gangs, further divided into four to five files, with each file further subdivided into four divisions of 10 men (Ezzamel 2004: 507). In the Middle Kingdom the Sinai Inscriptions indicate that the most common

from textual evidence that the size of these crews varied from 10-400 and therefore the number of foremen, skilled workers, guards, and porters also varied. This would influence the ration mix used in the algorithm. Four sizes of crews (13, 25, 55, and 85) with their respective ranks have been identified as the most representative of the majority found in accounting texts (summarised in the table below).

| Rank within crew | Assumed organisational profiles of the crews | | | |
|---|---|---|---|---|
| | **Profile 1** | **Profile 2** | **Profile 3** | **Profile 4** |
| Chief foreman | 1 | 1 | 2 | 2 |
| Skilled worker | 10 | 20 | 46 | 75 |
| Guard | 1 | 1 | 2 | 2 |
| Porter | 1 | 3 | 5 | 6 |
| **Crew size** | **13** | **25** | **55** | **85** |

**Table 7.12: Four organisational profiles of the ranks within crew 2**

## Assumption 3

The food rations for state non-basic crews have been set at 70% of the crews working from Deir el-Medina crews.[1237] This is a conservative assumption but still means the crews would have surplus grain for disposal over and above the 1,091 kg/annum required to feed himself and his family as shown in the table below. The negative number for the porter indicates that he required another part time job to make up the shortfall in rations to feed himself and his family.

| Rank within crew | Deir el-Medina tomb workers | Other non-agrarian state workers with rations @70% of Deir el Mna |
|---|---|---|
| Chief foreman | 3,836 | 2,340 |
| Skilled worker | 2,492 | 1,408 |
| Guard | 700 | 182 |
| Porter | -195 | -455 |

**Table 7.13: Surplus grain rations over requirements for crew families in Deir-el Medina assuming their rations were 70% of the Deir el-Medina necropolis crews**

The resulting surplus grain is given in the table below.

organisational unit for manual workers was 10 men controlled by a foreman.(Mueller 1975: 251-153). In reign of Ramesses IV the New Kingdom royal tomb builders at Deir el Medina had reached a peak of 120 though at other periods the crew was typically 40 strong organised into two gangs (Eyre 1987b: 174).

[1237] Lower rations are assumed because the Deir el-Medina royal necropolis workers were probably in a privileged position compared with other state workers.

| Rank within crew | Surplus rations for each crew kg/yr | | | |
|---|---|---|---|---|
| | Profile 1 | Profile 2 | Profile 3 | Profile 4 |
| Chief foreman | 2,340 | 2,340 | 4,680 | 4,680 |
| Skilled worker | 14,080 | 28,160 | 64,768 | 105,600 |
| Guard | 182 | 182 | 364 | 364 |
| Porter | -455 | -1,365 | -2,275 | -2,730 |
| **Total** | **16,147** | **29,317** | **67,537** | **107,914** |

**Table 7.14: Surplus grain entering informal economy kg/annum**

The total number of crews in this equation equals the size of the state workforce cohort divided by the crew size. For example for a cohort state workforce of 50,000, the size the number of crews = 50,000 ÷ 13 = 3,846. The number of crews for each assumed total number of state workforces for each of the assumed crew sizes is given in the table below.

| Size of assumed state workforce | Size of crew | | | |
|---|---|---|---|---|
| | Profile 1 | Profile 2 | Profile 3 | Profile 4 |
| | 13 | 25 | 55 | 85 |
| | Number of crews for a given size of state manual workers | | | |
| 50,000 | 3,846 | 2,000 | 909 | 588 |
| 100,000 | 7,692 | 4,000 | 1,818 | 1,176 |
| 200,000 | 15,385 | 8,000 | 3,636 | 2,353 |
| 300,000 | 23,077 | 12,000 | 5,455 | 3,529 |

**Table 7.15: Number of crews for each assumed size of state workforce for each assumed size of crew**

The surplus entering the informal market equal the surplus rations for each crew multiplied by the number of crews for each assumed crew size. For example for a cohort of 50,000 with 3,846 crews of 13 workers, the total surplus rations = 3,846 (see Table 7.15 above) × 16,147 = 62,101,362 kg of surplus food. All combinations of state workforce cohorts and surplus grain ration per assumed crew size are given in the table below.

| Size of assumed state workforce | Tot surplus grain kg entering the informal market | | | |
|---|---|---|---|---|
| | Profile 1 | Profile 2 | Profile 3 | Profile 4 |
| 50,000 | 62,101,362 | 58,634,000 | 61,391,133 | 63,453,432 |
| 100,000 | 124,202,724 | 117,268,000 | 122,782,266 | 126,906,864 |
| 200,000 | 248,421,595 | 234,536,000 | 245,564,532 | 253,921,642 |
| 300,000 | 372,624,319 | 351,804,000 | 368,414,335 | 380,828,506 |

**Table 7.16: Total surplus entering the informal economy**

The amount of surplus grain entering the informal market is considerable and is even more dramatic when these large numbers are converted into the equivalent number of

Ramesseum granaries which would have been needed. The scale of this informal market is shown in the table below.[1238]

| Size of assumed state workforce | Equivalent number of Ramesseum granaries if emmer wheat is stored | | | |
|---|---|---|---|---|
| | Profile 1 | Profile 2 | Profile 3 | Profile 4 |
| 50,000 | 4.9 | 4.6 | 4.8 | 5 |
| 100,000 | 9.8 | 9.2 | 9.6 | 10 |
| 200,000 | 19.5 | 18.4 | 19.3 | 19.9 |
| 300,000 | 29.3 | 27.6 | 28.9 | 29.9 |

| Size of assumed state workforce | Equivalent number of Ramesseum granaries if barley is stored | | | |
|---|---|---|---|---|
| | Profile 1 | Profile 2 | Profile 3 | Profile 4 |
| 50,000 | 6.2 | 5.8 | 6.1 | 6.3 |
| 100,000 | 12.3 | 11.6 | 12.2 | 12.6 |
| 200,000 | 24.6 | 23.3 | 24.4 | 25.2 |
| 300,000 | 37 | 34.9 | 36.5 | 37.8 |

**Table 7.17: Equivalent number of Ramesseum granaries**

The case study indicates that the quantity of grain circulating in the informal economy was equivalent to 4.9 granaries of wheat the size of the Ramesseum granaries (see again Figure 5.3) for the lowest assumption, a state workforce of 50,000. If the grain was barley 6.2 Ramesseum granaries would be required (see Report 3.21L in AGCALC).[1239] This would make the informal economy a thriving market of substantial size in its own right. If you add to this surplus, grain (after tax) taken from unattached craftsmen in the rural villages together with any surplus grain left over after the farmers had paid their tax dues to the state or temple estates, particularly in times of harvest glut, this informal market would be very large indeed. The size of this informal market taken together with the high level of interregional trade in the LBA is another key indicator that the LBA economy was not minimalist in nature. The fact that higher ranked workers and skilled workers were paid more than others meant that some workers became very rich indeed giving them opportunities of acquiring luxury goods to fulfil their own conspicuous consumption needs, perhaps leading to the formation of a sub-élite. The growth of a new sub-élite in the LBA economy will be the subject of the next section which also discusses the possibility that the growth of conspicuous consumption within a sub-élite social class may have led to the formation of an embryonic formalist economy.

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1238 Table 7.16 uses the results from the last chapter that the Ramesseum could hold 16,552 $m^3$ of grain, which would weigh for wheat and barley 12,728,488 and 10,080,168 kg respectively. The dry density of dry emmer wheat and barley has been taken as 769 and 609 $kg/m^3$.

1239 See Report 3.21i in AGCALC for assumptions and analysis.

## 7.5.2 The demand for conspicuous consumption outside of the élite

Several scholars have proposed that the increased wealth moving down the social scale of LBA society formed a 'sub-élite' creating a demand for objects that emulated the conspicuous consumption of the ruling élite and which gave them prestige in the eyes of their contemporaries. S. Sherratt proposes that the Cypriot pottery in the pithoi on the Ulu Burun wreck was destined for a sub-elite market (Figure 7.26).[1240] The last section has shown that non-basic skilled workers and their supervisors in Egypt had surplus grain that they could use to acquire luxury items to satisfy their own conspicuous consumption aspirations. This section will examine the textual and archaeological evidence for luxury goods in non-élite contexts particularly those entering the informal economy directly or indirectly as a result of interregional trade. We know from the evidence of the Ulu Burun, Gelidonya, and Point Iria Wrecks that some relatively low value manufactured goods and raw materials were carried in the ships' manifest: Cypriot pottery, foodstuffs, faience beads, exotica (ostrich, tortoise shells), weapons, tools, bronze objects, and scrap metal for recycling were being transported. While the main cargo in the Ulu Burun wreck, 10 tons of copper, one ton of tin, and one tin of pistacia resin were probably state sponsored trade, it seems likely that these other items were traded for profitable speculative exchange by the ships crew as the boats move from harbour to harbour around the Central and Eastern Mediterranean.[1241]

Modern scholarship is moving away from interpreting imported pottery as being exclusively pieces of fine ware destined for the ruling élite. Increasingly pottery is seen as entrepreneurial space fillers between the commodity cargoes as first proposed by Gill.[1242] This is suggested by Cypriot pottery, particularly white slip ware, base ring bowls, and large storage jars which are found extensively across both Central

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[1240] Sherratt 1994: 67-68 and Sherratt 2000: 83. Pithoi on the Ulu Burun wreck contained Cypriot Base Ring and White slip bowls, wide-mouthed jugs, clay lamps, and wall brackets.

[1241] Pulak 2001: 40-45, Bass 1967a, and Lolos 1999: 43-58.

[1242] Gill 1991: 29-47 and Gill 1994: 105-107. Also see Artzy 2001: 107-116 show large clusters of White Slip ware close to ports along the Carmel coast of Israel. Similar findings along the Northern Levantine coast support the same argument. For a contrary position see Boardman 1988: 27-33.

and Eastern Mediterranean.[1243] White slip ware (particularly LC IIC) has been chosen as an example of these entrepreneurial space fillers as it is particularly widespread and pertinent to the period under consideration. White slip ware and other pottery types found in the Eastern and Central Mediterranean have been comprehensively covered by Bell, Bergoffen, Hankey, Leonard, Merrillees, van Wijngaarden, and Yon.[1244]

White Slip II, particularly WS II late, was a lower quality than White Slip I. This has led Yon to conclude from her analysis of white slipware in Northern Levant that:

> … Another striking feature is the vulgarization of White Slip which became a utilitarian ware at the end of the Late Bronze Age …White Slip was no longer the merchandise of a luxury trade [for the ruling élite], but rather a mass-produced ordinary type of pottery which was no doubt sold at a moderate price.[1245]

The resulting deterioration in standards (poor slip preparation, compromising on the materials used) and applying the paint with a multiple brush as well as simplifying the designs, meant a lot more could be produced in a shorter time, thus lowering production costs due to using a mass production process.[1246] It was probably not the drop in quality that makes them more affordable, but the increase in quantity that made them more widely available to the sub-élite. White Slip II pottery is exactly the type of product likely to have been favoured by the emerging sub-élite to underpin their status of those around them. It would have status because early imports of White Slip I were of high quality and well known because it has been found in all parts of the Eastern Mediterranean from the Aegean to Marsa Matrouh, but the drop in quality and increase in quantity would have made them affordable. The widespread finds of white slipware outside of ruling élite contexts led Artzy to make this ironic comment:

> White Slip ware was but one more element in this new, or newer type of trade. It probably became a prestige object for the new 'sub-élite', and one could not survive the neighbours' stare without at least one White Slip bowl covering the store jar.[1247]

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[1243] Artzy 2001: 107-116, Hatcher 2007, Karageorghis 2001: 9-14, Merrillees 2001: 89-100, Vagnetti 2001: 101-106, White 2003: 71-83, and Yon 2001: 117-126.
[1244] Bell 2006, Bergoffen 1991: 64-73, Hankey 1995: 116-126, Leonard 1994, Merrillees 1968, van Wijngaarden 2002, and Yon 2001: 117-126.
[1245] Yon 2001: 123.
[1246] Artzy 2001: 112.and Hatcher 2007: 143.
[1247] Artzy 2001: 114.

## 7.5.3 Summary

This section has argued that the informal economies of New Kingdom Egypt, Cyprus, and Ugarit were sufficiently large for wealth to have aggregated and form a sub-élite who sought goods to display their rising social position. In Egypt this was all part of a growing democratisation of religion and social position.[1248] Across the Eastern Mediterranean land was increasingly privately owned either through gifts from the king particularly in the case of Egypt or from the wealth created in the case of Ugarit and Cyprus by a merchant class that had become rich from maximising returns from maritime and overland trade. In itself the evidence for luxuries, particularly those from overseas trade, does not prove that a formalist market had developed. We do know that this 'piggyback' trade carried by maritime vessels was not regulated in the manner noted in State infrastructure projects. In this unregulated modus operandi, a parallel maritime based market could have developed that had built within it the opportunity to respond to a growing demand for luxury products. This response to a demand for non-essential goods further down the social scale running in parallel with administered commodity trade could have been the first steps in the formation of an embryonic market. The next section will consider if there is sufficient evidence that the 'prices' of goods exchanged were influenced by the law of supply and demand.

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[1248] Baines 1987: 79-97, Finnestad 1988: 89-93, and Sørensen 1988: 109-125.

# 7.6 Value, price, and profit

The purpose of this section is to assess whether the concepts of value, price, and profit in the LBA have the same meaning they do in post Neo-Classical economics. The textual evidence will be reviewed to see if the price of goods, staples, and commodities did vary in times of shortage or glut. The final discussion point will be the role of reciprocity in the LBA economy, which is a substantive concept, to see if the practice of reciprocity was so embedded in the interactions between ruling élites any embryonic formalist market would have been stifled.

## 7.6.1 Defining value

To facilitate the exchange of goods both parties to that exchange must have a common understanding of the value of the transaction. Value was not intrinsic to the object, but a judgement made about it by society.[1249] It therefore has two dimensions a rational element and an irrational element.

### The rational characteristics of value

The cost in terms of the manpower to feed the non-agrarian workers would have been a major factor in assessing the value of the product. As noted even the raw materials that used to make added-value goods can be related back to the manpower required to produce them. To ensure economic stability over the long term, the cost of imports must at a minimum balance. A positive balance would increase the underlying growth of the economy. This thesis postulates that the value placed on large commodity items such as copper and tin ingots, when exchanged, would have to be at a minimum recovered. The importance of this is demonstrated in the findings of the modelling carried out and discussed in Section 7.2 related to the scale of the LBA economy. The analysis showed that in times of average harvests Egypt could dedicate 293,000 workers to state infrastructure projects and the production of products for conspicuous consumption, for Cyprus this number is much lower with 10,900 workers. Section 7.2.1 above has shown that 40 percent of harvests might fail to meet the average harvest yield required to support these 10,900 Cypriot workers

[1249] van Wijngaarden 1999a: 3 citing Simmel 1922: 5-8; 20; 46.

most of which would have been working in the copper industry.[1250] With this degree of vulnerability it is unlikely that Cyprus, with a low population in the LBA, could have participated in the interregional copper trade without at least covering its manpower production costs. 'Exchange' in this sense is not the same as gift exchange between regional élites as a different set of values comes into play in gift exchange such as prestige and obligation. In gift exchange the respective receiver and giver of the gifts would evaluate and place a value on the gift that was based on their own respective political and domestic agendas.

**Metrology and value**

This section will discuss the need for a method to transfer values across regional boundaries. The evidence for proto-currencies will also be examined to see whether they acted in the same manner as coinage, in both the informal market and inter-regional trade.

Some level of objectivity in determining value of goods traded must have been present, particularly in the trade of commodities and staples. The archaeological record has a rich source of evidence showing that standardised weights were used in the pursuit of trade.[1251] It is not intended to present in detail the archaeological evidence of the weights and volume measures found in LBA contexts, as this evidence has been scholarly analysed and published before.[1252] Rather this section asserts that there was a rational mathematical progression within each regions systems of weight and it is this rational attribute that enabled one merchant from one region to understand the standardised weights of another. The commonality in shape and design as well as their mathematical relationship within the assemblage, and between them, must surely be more than a coincidence. The mathematical relationship within weight assemblage's progression for different regions can be seen

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[1250] The metals industry was very demanding in manpower requirements. Report 6.1a in BRONZECALC shows that 134 man-days were required to make one kg of copper.

[1251] Alberti and Parise 2005: 381-395, Hafford 2001: 185-291, Michailidou 1999: 87-113, Petruso 1984: 293-304 and Petruso 2003: 285-292.

[1252] For an overview of weight systems in the Bronze Age East Mediterranean see Lassen 2000: 233-246.and more generally Mederos and Lamberg-Karlovsky 2004: 199-214. See Pulak 2000b: 247-279 for an analysis of the 149 weights and scales carried by merchants on the Uluburun and Bass 1967d: 135-141. For the Mesopotamian weight metrology see Powell 1979: 71-89 and Young 1979: 195-217. For weights relating to Aegean merchants see Michailidou 1999: 87-113; Michailidou 2003: 301-316; Michailidou 2004: 311-322 and Michailidou 2005.

in this example. The Hittites, Ugaritarians, and Syrians all had a common unit of a talent (28.2 kg) and a mina that was 1/60th of a talent (0.47 kg). The Hittites, Ugaritarians, and Syrians each had a different shekel equivalent to 1/40th, 1/50th, and 1/60th of a mina respectively. This gives a series of values and the differences which could be easily accommodated because merchants would have understood the underlying logic as shown below. This is clearly demonstrated in the table below showing the mathematical cross-cultural relationships in separate metrology systems. Polanyi clearly disagreed with this concept as when evaluating the Mycenaean Linear B administration he concluded that one kind of product could never be equated with, or substituted for, an amount of goods of a different kind.[1253]

| Weight unit | Weight gms | Mathematical relationship | | | | |
|---|---|---|---|---|---|---|
| Talent | 28,200 | 1 | | | | |
| Mina | 470 | 60 | 1 | | | |
| Hittite shekel | 11.5 | 2400 | 40 | 1 | | |
| Ugaritarian shekel | 9.4 | 3000 | 50 | 5/4 | 1 | |
| Syrian shekel (Alalakh) | 7.83 | 3600 | 60 | 3/2 | 6/5 | 1 |

**Table 7.18: The mathematical relationship between Hittite, Ugaritarian, and Syrian weights**

The Gelidonya wreck had at least seven different weight standards and the Ulu Burun wreck had three. The largest unit known from this period is the talent, weighing approximately 28-29 kg and it was probably used for weighing larger items such as copper ingots. There were different sets of weights assemblages on both the Gelidonya and Ulu Burun wrecks indicating that the ship's captain understood the cross cultural relationship between weight and value.

The Egyptians used value comparators such as the *deben* and the sack in two ways. They were used to compare different values of items for barter but they also had a 'use value' as weights in the case of the *deben* and a measurement of volume of grain in the case of the sack.[1254] Use value is perfectly rational but it is quite "un economic" from a Neo-classical perspective.[1255]

[1253] Polanyi 1960: 342.
[1254] Janssen 1988: 13-14. In the New Kingdom the copper deben weighed 91 grams divided into 10 qdt. In the New Kingdom a sack (khar in Egyptian had a volume of 76.8 litres.
[1255] Janssen 1988: 15.

## Irrational characteristics of value

Other aspects which influenced the value of traded goods are the distance between producer and consumer, their functionality, and for non-commodity items some degree of subjective value resulting from their 'foreignness'.[1256] Cline commenting on the ceramic wall brackets found in Tiryns states:

> [The wall brackets] ... were desirable enough to be purchased despite their 'irrationality' and redundancy precisely because they were foreign goods with a 'distance value' – made exotic by the distance which they travelled.[1257]

Some material goods may therefore carry a premium over and above their expected value because they are fashionable or have an air of mystery.[1258] Simmel states that value is not just a property of an object, but a judgement made about it by people.[1259] Meskell provides a salutary reminder that we must be aware of our own subjectivity when attempting to understand the value of artefacts from the past. Modern society tends to value objects because of their rarity and devalue those that are abundant and easy to extract and this attitude may be totally different from the ancients' perception of value.[1260] However with some elements of subjectivity, the whole concept of conspicuous consumption would be negated. The élite collected rare and exotic goods in order to define their place in their own domain and as importantly, for this period of increasing contact between regions, their status in the eyes of other regional élites. Goods exchanged to satisfy conspicuous consumption needs have a value greater than their functional value because they possess desirable characteristics that reflect the tastes and aspirations within that society.[1261]

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[1256] Functionality, in the sense of the practical advantages it gave the user, was particularly important in the field of weapons and tools. Obsidian was traded throughout the Bronze Age and Iron Ages as no metal knife could match its cutting powers. Similarly the chariot and scimitar sword became universal across the Eastern Mediterranean because without them respective armies could not compete.

[1257] Cline 1999: 123. Mary Helms has suggested foreign goods could be used by the élite as a source of secret knowledge to which only they had access and understood. Exotic goods had magical and religious significance because they came from outside the normal experience of the rest of society. She cites spices and incense as examples of substances with divine association because they were from far away. The public display of these exotic goods from distant lands demonstrated the importance and status of the owner through his contact with foreigners (Helms 1993: 164-165).

[1258] Van Wijngaarden 1999b: 10.

[1259] Simmel 1922: 5-8; 20; 46.

[1260] Meskell: 2004: 18.

[1261] These characteristics could span many things; colour, design, shape, opulence, smell, touch or religious association or sheer opulence but it is these attributes that create an emotional response that give the object abstract meaning and value (Gosden 2004: 33-40).

The value of a commodity is easier to determine than that of a luxury item.[1262] Section 7.4 above has demonstrated that the Egyptians used a cost accounting methodology that in theory would allow them to quantify the effort that went into the production, and therefore its value when exchanged for other commodities or staples. If they used cost accounting for this purpose then placing a value on a good or service traded would have been the result of an objective and rational process in a formalist sense. Whether or not they used cost accounting in this manner will be returned to in the next section. The value of non-commodities is more subjective because their values reflect the culture that requires them and varies from one culture to another. This reflects a substantive view of the economy. The textual evidence for the price of fine and domestic pottery in the LBA is particularly sparse which is surprising as the archaeological record is extensive and provides a valuable barometer for the level of international contact.[1263] This may reflect the possibility that pottery such as White Slip ware operated outside of state administered trade.

To summarise, value is a complex combination of both rational and irrational elements. It is the different types of "ends" to which economic organisation and control are directed that lead to different scales of "values".[1264] The use of rational and objective systems of standardised weights however based on mathematical progressions gave traders from different regions a method of quantifying the weight and volume of goods from anywhere in the Central and Eastern Mediterranean that

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[1262] Knapp 1988b: 152 has provided a useful definition of a commodity, in that it has an economic and a utilitarian value. A luxury item is related to conspicuous consumption with a social and non utilitarian value.

[1263] Sherratt 1999: 184-185. A number of researchers have attempted to analyse the price of fine goods using different methodologies. Graziadio 1991: 403-440 uses a multivariate statistical approach that compares the composition of grave assemblages in terms of total number, range of artefacts and attempts to place a value on them by comparing them with functionally equivalent objects. Lewartowski 2000: 20-61 places less emphasis on the value of the object itself but instead allocates hierarchical status indices to objects and ranks them within the same assemblage. A sword would have a ranking of 15 and storage pottery a ranking of 1. This approach is subjective but if consistently applied across a number of tombs will give a relative if not an absolute measure of wealth. Hulin 2006: 180-186; Table 5.2 has created an innovative relative wealth index of LBA artefacts excavated in Beth Shean. Hulin value analysis uses the evidence of two textual records from Ugarit: the cost of one *mḳdm*, or flask that cost 1/5 shekel of silver and 50 *hrsh*, or bowls that could be purchased for 1 shekel of silver. Using size, decoration, and function as evaluation criteria she extrapolates and interpolates the prices from the texts to estimate the value of the Beth Shan tomb assemblages. The difficulty with all these approaches, with the possible exception of Hulin's approach, is that they apply our sense of value to the ancients.

[1264] Firth 1950: 5.

would have facilitated greater trust between interested trading parties approaching exchange with different values.

In the next section these weights which can be considered as 'value comparators' are shown to have played a key role in determining the prices of goods traded within the informal and interregional markets.

## 7.6.2 Defining price, profit, and proto-currency in the LBA

Closely linked to cost and value are price and profit. This section will examine the evidence to determine if the price of a commodity exchanged had within it an element of profit. Central to the debate on prices is whether interregional trade was state administered and/or involved private initiatives. Polanyi did not deny there was such a concept as 'price' in antiquity, though he preferred the term 'trading rate', which was used for the purposes of facilitating exchange. He differs fundamentally from formalists by arguing that commodity prices were set by price-fixing authorities acting through ports of trade and not by market supply and demand mechanisms.[1265] Snell's analysis of the UR III silver balanced accounts for a range of goods traded over a long period could find no correlation between price and that expected from Neo-classical price-demand curves.[1266] Snell concludes that price variation reflect a hierarchy of values that a civilisation considered important.[1267] Ethnographic evidence from West Africa shows that prices need not be set by price-fixing authorities as small independent groups of sellers agree prices in the short term to prevent instability in the market caused by undercutting each other.[1268] Polanyi's assertion that price had a different meaning in antiquity is shared by Janssen who is of the opinion that price in antiquity did not have the precise meaning it has in modern society.[1269]

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[1265] Polanyi 1957a: 255, 266-269. Polanyi viewed the port of trade as the "site of all administered foreign trade" (Polanyi 1957a: 263). Polanyi suggested that Ugarit and Al Mina were ports of trade (Polanyi 1963: 30).

[1266] Snell 1982: 190, Table 34. Rather than following the Neo-Classical price-demand curve more raisons were purchased when the price was high. Silver balanced accounts are discussed below.

[1267] Snell 1982: 207.

[1268] Humphreys 1969: 188 citing Bauer 1954: 191.

[1269] Janssen 1975a: 515.

There is ample textual evidence from Ugarit that metals did have a value relative to each other but the stability of these prices within this region indicates that commodity metal prices were not significantly influenced by the forces of supply and demand.[1270] Silver prices relative to copper did vary in the Ramesside period from 1:100 to 1:60 that could have been caused by a flood of silver from extensive tomb robbing in the New Kingdom.[1271] If so this suggests that market forces were reacting to supply and demand pressures. Textual evidence shows that the prices of goods did vary between regions.[1272]

Explicit textual evidence for financial transactions is limited for LBA Cyprus to Cypro-Minoan proto-script.[1273] Heltzer's scholarly work on the prices of goods in Ugarit and surrounding regions show that prices were recorded.[1274] The close proximity of Cyprus (72 km) means that evidence from Ugarit will be used in this study. Textual evidence of prices in Egypt is particularly limited outside of Deir el-Medina, and no texts relate to profit made in local marketplace trade.[1275]

Textual evidence for Old Assyrian tin and textile caravan trade show that a gross profit was made on the sale of tin.[1276] The average textile purchase price in Aššur was 5-6 shekels of silver but the selling price varied significantly between 10-21 shekels but on average 15 shekels of silver apiece.[1277] Ur II texts and the Larsa texts written immediately following the collapse of the UR III dynasty were 'silver balanced accounts' that were give formulaic statements of the merchant's value of assets at the start of the trading period in silver shekels and the merchant's expenses in silver equivalent. The resulting balance is noted as well and transferred to the next

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[1270] Heltzer 1977: 203-211 with full references. The texts show exchange rates of the following metals as: silver to tin 1:227; silver to copper (or bronze as the texts are not clear on this point) is within the range 1:200 to 1: 235, and gold to silver was between 1:3 and 1:4 (Heltzer 1977: 204).
[1271] Kemp 2006: 319.
[1272] Yannai 1984: 19 analyses the source data in Heltzer 1978: 99-78 and shows that horses were the cheapest in the Hittite empire followed by Nuzi, timber was cheaper in Ugarit than in Mesopotamia, and gold from Egypt was the cheapest in the Eastern Mediterranean.
[1273] Pulak 1998: 196 proposes that the Cypro-Minoan marks on the copper and tin ingots indicate a proto way-bill linking shippers, consignees, and destination for the ingots. Kassianidou 2003a: 115-117 links these marks on the ingots to those found on Cypriot pots and Aegean pots in many parts of the north-east Mediterranean (analysed by Hirschfield 1993: 311-318 and Hirschfield 2000: 163-200). For an analysis of the Cypro-Minoan script found on the Uluburun ingots see Sibella 1996: 9-11.
[1274] Heltzer 1977: 203-211 and Heltzer 1978.
[1275] Janssen 1988: 20-21.
[1276] Veenhof 1972: 82.
[1277] Veenhof 1972: 83-85.

account. This bookkeeping procedure does not however explicitly highlight profit made although it can be implied (Figures 7.27).[1278] The profit levels above are Veenhof's own analysis of the ancient accounts, not a statement of profit made by the merchants concerned. These accounts acted therefore in a similar manner to modern cash flow analysis (a bank statement is a good example) rather than profit and loss accounts.[1279] Silver however proposes that the 19th century B.C. Babylonian word *nēmulum* is equivalent in sense to the modern day equivalent for profit.[1280] Powell also strongly defends the case that merchants in Mesopotamia were motivated by profit but does concede it was not their sole motive.[1281] In summary the evidence is insufficient to conclude that we can equate the Mesopotamian term lá-NI (balance) with profit.

In Egypt the textual record for the LBA seems to indicate reasonable price stability for grain, ranging between 1-2 *deben* per khar for most of the New Kingdom. This suggests that there was some form of the direct price control by the administration and/or the indirect control of the fluctuations in demand, by the grain buffer in the state granaries.[1282] There are a few notable exceptions in that the price of emmer wheat and barley did rise dramatically from the end of the Nineteenth until the middle of the Twentieth Dynasty. In regnal year 7 in the reign of Ramesses VI (1153-1141 B.C.) or possibly Ramesses VII (1143-1136 B.C.) emmer wheat rose in price to 4 *deben* per khar, with one text reaching 8 *deben* per khar.[1283] It is not possible to link these price changes to supply and demand because texts for the corresponding periods do not give any indications of harvest failures. Janssen did not

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[1278] Leemans 1954: 43-51 especially 49-51 and Young 1979: 197-201. The silver balanced account comprised four sections: (1) Statement of assets all equated to current value of silver, (2) Record of expenditures including statement of either a credit balance (LAL.NI) or an overdraft (dirig), (3) Statement of responsibility, and (4) the date. For a contrary position see Powell 1977: 23-29 discussed below.

[1279] As this was a pre-monetary society the account ledgers were measure the flow of silver, actual or the silver equivalent of the goods purchased or sold, in and out of the merchants account.

[1280] Silver 1985b: 88.

[1281] Powell 1977: 24 ff. He argues the vast corpus of Mesopotamian texts that have survived distort the picture because they are internal reports of the palace and temples. As a result they focus on the expenditure and income from these estates. He challenges the majority view of scholars that ownership of "private property" was minimal. He defends the case that many merchants were not under the control of the state and therefore their personal records reflecting formalist entrepreneurship are not found within the state and palace archives. He concludes that the term 'balance' UR II accounts was interpreted by the administration as profit.

[1282] Kemp 1991: 252.

[1283] Kemp 1991: 252 and O'Connor 1983: 226-229.

believe this was due to market forces and proposes that the most likely cause for price fluctuations was a malfunction and corruption in Egypt's redistribution system; attested embezzlement of temple grain in the reigns of Ramesses II-V, and payment of state workers in arrears that led to strikes in Deir el-Medina throughout the reigns of Ramesses III to Ramesses X.[1284] Many Egyptian tombs show market place scenes which might be evidence of a market economy barter which dictated price levels of goods bought and sold (Figure 7.28).[1285] Bleiberg takes a substantive perspective of the operation of the market place shown in Egyptian tombs describing them as "semi-organized barter" suggesting that even local markets were institutionally embedded.[1286] In reality a more likely outcome was the recognition that for the informal market to work effectively and maintain stability, prices were self regulated to ensure bands of 'fair prices' were maintained within the bartering process, thus ensuring the interests of buyer and seller were not exploited. This process is substantive in nature.[1287] In Egypt this practice would be perfectly compatible with their religious belief in the necessity to maintain order through the maintenance of *Maat* and prevent the nation descending into chaos.[1288]

The LBA Ugarit texts show that the silver shekel was used as a value comparator to determine the relative price of a product exchanged and in every sense acted as a form of proto-currency. This practice of using the shekel as a unit of account continued right up to the Kingdoms destruction in ca. 1178 B.C.[1289] Bullion and rare metal objects were also used as a form of proto-currency. Powell's analyses of the weights of silver rings and coils found in the Mesopotamian archaeological record demonstrate that they have an underlying metrological statistical relationship. He

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[1284] Janssen 1975a: 551-552 citing evidence from Cerný, J. 1957. *Hieratic Ostraca* Vol. 1: 36,1, vs. 5. Oxford: Printed for the Griffith Institute at the University Press and Pap. Turin 1907/8.
[1285] Tombs of Kenamun and Ipy (Kemp 1991: 254, Figure 86 with full references).
[1286] Bleiberg 1995: 1383.
[1287] Humphreys 1969: 189-190.
[1288] The concept of *Maat* or 'social order' was fundamental to the Ancient Egyptian. Maintaining 'the way things are done' was of prime performance.
[1289] Heltzer 1979: 477, Hafford 2001: 110-111, and Muhly 1995: 1487-1497 for the use of proto-currency in Mesopotamia internal and external exchange. Goddeeris 2002: 390 citing Renger 1995: 271-274, 282-283 who defines proto-currency in antiquity as commodities which fulfil four functions:

1. As a means of exchange.
2. As a means to fulfil certain tax liabilities (taxes and ceremonial obligations).
3. As a means to compare values of different commodities.
4. As a means to store accumulated wealth.

proposes that they were used as a form of money in the Late Babylonian period.[1290] Vickers and Gill proposed that precious metal scrap and bullion and even fine art metal objects were used in antiquity over a long period as a form of proto-currency.[1291] Silver discusses the possibility of silver weights of fixed weights carried in the first half of the second millennium in official sealed and labelled purses of silver (*kaspum kankum*) that acted as a form of proto-currency.[1292] Powell is in no doubt that staples such as barley and commodity metals such as silver were used as 'money' in LBA Mesopotamia.[1293] Powell argues that the mina and the shekel were originally Mesopotamian weight-metrological terms that evolved into monetary units used not only informally but also appeared as monetary units in other languages.[1294] Sherratt succinctly sums up the use of proto-currency in the LBA:

> In the second Millennium, precious and base metals, primarily gold, silver, copper and tin, represent what may be regarded as prime or convertible value, within the exchange systems of the eastern half of the Mediterranean.[1295]

## 7.6.3 The role of merchants in the LBA economy

Merchants have always been at the centre of trading negotiations and examining the textual evidence relating to their status, role, organisation, and their modus operandi may indicate whether they operated independently to maximise a return of profit or whether they were controlled and managed within the institutions of the state. The evidence for their independence from the state goes to the heart of the formalist - substantive debate. Polanyi's states quite emphatically that all merchants were agents of the state and not salesmen motivated by gaining wealth through profitable trading transactions.[1296] This section will examine the evidence to test Polanyi's hypothesis and specifically to see if there was a class of merchants whose independent activities satisfied the demand for luxury goods for an emerging sub-élite.

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[1290] Powell 1978: 211-244.
[1291] Vickers and Gill 1994: 40-42 and Gill 2008: 336-344.
[1292] True coinage did not appear in the Eastern Mediterranean until the 7th century B.C in the Anatolian Kingdom of Lydia. This was followed in 630 B.C. by the Greek city-state of Aegina (Silver 1985b: 87-88, 126-130).
[1293] Powell 1996: 228.
[1294] Powell 1990b: 508-517 and Powell 1996: 228.
[1295] Sherratt 2000: 83.
[1296] "... [their] livelihood [of merchants] was not dependent on the commercial transaction in hand; it was secured by status revenue, mostly through landed property or at least through the claim to maintenance according to his rank from the royal or temple store ... This is a far cry from the modern merchant who makes a living from the differences between buying and selling prices ..." (Polanyi and Pearson 1977: xliii, 87, 138-139).

The main source of evidence will be the LBA economic texts from Ugarit as they are contemporary with the period under study and are the most extensive texts relating specifically to merchants and trade. Ugarit although being relatively small in terms of land area, 2000 km$^2$ and a population ca. 25,000, was a principle centre of commerce of the Eastern Mediterranean in the LBA.[1297] Determining the status of merchants in Ugarit is problematical for two reasons: firstly Ugaritic texts are generally vague when it comes to clarifying social positions in Ugarit society; secondly the large numbers of foreign merchants living in Ugarit make it difficult to decipher the hierarchy of the merchant community as a whole.[1298] There were a large number of foreign merchants who lived in a special district in the immediate vicinity of Ugarit's main harbour Minet el-Beida under the supervision of the *akil kar-ri*, 'overseer of the merchant colony'.[1299] The greatest numbers of foreign merchants in Ugarit were those from Ura, a seaport on the Cilician coast and were called the *tamārū Ura* (Merchants of Ura) acting under the direction of the King of the Hittites. Canaanite, Egyptian, Assyrian and Hittite merchants are known from texts.[1300] The common Ugarit term for merchant was *tamkārū*, or in the Semitic form *mkrm* and Akkadian *bdlm*. Ugarit's own merchants received rations from the state of which oil played an important part if the numbers of oil lists that have survived are representative.[1301] They also received allocations of land with full ownership rights that could be inherited by their sons for services rendered to the state as merchants.[1302] Astour's scholarly review of the Ugarit texts indicates that a small number of merchants were from a very high status *mariannu* class who combined the roles of trader and warrior.[1303] They owned some of the largest estates in the kingdom but they were not

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[1297] Calvet 2007: 108. The contribution that Ugarit made to the trading infrastructure that supported the unprecedented level of trade seen in the period 1400-1200 B.C. was covered previously in Section 6.3 when the LBA economy of the Eastern Mediterranean was discussed from a world-systems perspective.

[1298] Astour 1972:11 and Astour 1981: 25-26.

[1299] Rainey 1963b: 319 and von Soden 1972: 451-452.

[1300] Texts UT 311:1, 7,8; UT 1089:7, 10; and UT 1090:4, 9 (Rainey 1963a: 43).

[1301] Rainey 1963b: 313-314.

[1302] Heltzer 1978: 124 citing the text PRU, VI, 30 relating to the case of a service reward of land given by the king to the merchant *Abdiḫagab*, "and the service of *tamkar*ship he shall perform. Further: [?] the service of *tamkar*ship is performed by *Abdiḫagab*, nobody shall take away (these lands) from *Abdiḫagab* and from his sons and grandsons forever. The seal of the great king Iluramu, the scribe".

[1303] To be admitted to the high status *mariannu* class required their credentials similar to the later *hippeus* in Athens: a sufficient census; possession of at least one horse; and official confirmation by the state (Astour 1972: 14). Texts show that three named merchants were owners of salt works, others part of the hereditary ruling élite despite acting as advisors to the king and in senior administrative positions.[1304]

Some of the merchants may have been the personal envoys or royal messengers as indicated by the Amarna letter EA34 written by the King of Alašiya to the Egyptian king pleading for the return of a messenger. The Akkadian word *mār šipri* means 'representatives of his lord at the court of a foreign potentate'.[1305] The Austrian Archaeological Institute excavation at Qantir Pi-Ramesses site in the Delta has discovered direct epigraphic evidence for the presence of envoys in Egypt. It comes from Hermitage 1116A a papyrus dated to the reign of Tuthmosis III which lists the rations of beer and grain given to the envoys from 11 towns from the Levant and Canaan.[1306] This implies that trading missions and ambassadors were exchanged between them. Pusch suggests that these more permanent residencies acted like modern diplomatic embassies facilitating trading treaties and other agreements to maintain peace and increase prosperity cross the regions, and this is a substantive concept.[1307]

Gift exchange played a key part in this diplomatic activity which is contrary to the workings normally associated with a formalist economy. Products moving from region to region would have operated outside the price regulating mechanisms and would have had the effect of in part of dampening market demand even for

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owned horses, chariots, and land in their own right (Astour 1972: 12-15). One merchant named *Ybmn* even rose to the rank of governor of a district in the south western district of the kingdom (Astour 1972: 15).

1304 Astour 1972: 26 says that the closest parallel to the *mariannu* in historical times were the mercantile oligarchy in Venice. One of the richest merchants known was called Sinnaranu who paid 4,200 shekels for a property (Rainey 1963b: 315-316 gives all the key textual references).

1305 Oller 1995: 1466-1468. The word *mār šipri* does however have a wide range of meanings: messengers, diplomat, envoys, ambassadors, agent, deputy, and merchant. The *mār šipri* often brought gifts from his lord to the other either as exchange between equals or tribute from vassal states. Travel was dangerous at all times in antiquity whether by land or sea. Attacks were frequent from pirates and brigands as well as the hardship of the physical environment. To assist their passage "passports" were commonly issued by their rulers stating their name, position, to whom they represented and the purpose of visit. Diplomatic protocol meant it was common for the representative when completing his mission to be accompanied back with an escort to facilitate his journey back (*ālikidi* in Akkadian). He in turn would commonly return back with a message which ensured a continuous dialogue between ruling élites.

1306 Epstein 1963: 49-56.

1307 Pusch 1989a: 76-113; Pusch 1989b: 145-170 and Pusch 2005. Pusch is the Director of the Austrian Archaeological Institute with responsibility for the excavations of the Qantir Pi-Ramesses site in the Delta.

commodities such as copper and tin.[1308] Janssen and Schloen both believe that reciprocity played a part in exchange between households, friends, and neighbours in both Egypt and Mesopotamia, which Janssen defines as "gift giving". Janssen suggests that within a framework of kinship, individuals could obtain from their households etc what they required and in the process became their debtors. At the same time, each household etc also acted as creditors to others. The aim was not to get a balanced position but within the process allow obligations to be built up within the changing flux of creditors and debtors. Janssen considers the modern equivalent would be an 'open credit system'.[1309] Bourdieu rejects any formalist interpretation of this form of gift exchange as rational economic choice between scarce means. He introduces an element of time into gift exchange:

> "... the lapse of time interposed is what enables the gift or counter gift to be seen and experienced as an inaugural act of generosity, without any past or future, i.e. without calculation ..."[1310]

Manning and Hulin take the substantive view that merchants were not high status members of the élite. They argue that because the top echelons of the élite controlled and consumed the bulk outcomes of trade, necessitated them to control the status of merchants in such a manner that their social position was not undermined.[1311] Trigger presents a similar picture of Mesopotamian merchants who although affluent, were set apart from the urban élite, working, and possibly living, in a walled-off harbour (*karum*) outside of the city walls.[1312] One group of merchants in Ugarit identified in the texts as *bnš mlk* was in this category of low status merchants who lived on land plots provided by the king from his royal estates. In return for the right to be a trader they had to serve the king in time of war using their own weapons.[1313] Heltzer disagrees with Astour's interpretation of *bnš mlk* as peasant traders because the proportion of merchants in Ugarit society would be excessive. Instead he sees this

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1308 These gifts could be substantial in value and volume noted earlier.
1309 Janssen 1988: 16 and Schloen 2001: 79-83, particularly 82. Janssen suggests the nearest modern equivalent would be the "open credit" system.
1310 Bourdieu 1977: 171ff and Schloen 2001: 82.
1311 Manning and Hulin 2005: 271.
1312 Trigger 2003: 349-351. This has striking similarities to the status of the urban Jewish ghettos found around European cities from the medieval period onwards.
1313 Astour draws parallels with the peasants living on land owned by the Imperial Family in Nineteenth century Russia. These peasants could buy a 'trading certificate' and were then counted as "peasants dealing in commerce" (Astour 1972: 22 and footnotes 147-153 with full textual references, 26).

category of merchants though of a lower status than the *mariannu* should be placed in the same category as the other 32 professional groups identified in the Ugarit texts.[1314] This would support the substantive view that merchants were agents of the state, not independent traders.

The evidence above clearly supports Polanyi's view that merchants were servants of the state, with formal positions and their associated high status embedded and enmeshed in the institutions of the state. There is however some limited evidence that some of the merchants were free to pursue independent trading outside of the state system. For example the merchants of Ura were given silver for private enterprises:

> … received certain sums of silver, but that further commercial transactions were on their own.[1315]

The only other opportunity for a more formalist free trade is associated with entrepreneurial trade carried by the sailors as 'fill in' trade noted above. There is no textual evidence to support the presence of 'free trade' in Ugarit but we can speculate that it is more likely that this 'piggy back' trade would have passed through the hands of the foreign resident merchants living in the immediate vicinity of the harbour. The lack of textual evidence of harbour dues or taxes for products such as White Slip ware suggests that they were not official which officialdom probably chose to ignore. They had more opportunity for speculative trading on the quayside provided they paid between them harbour dues and local taxes and/or 'baksheesh' to oil the wheels of bureaucracy.

## 7.6.4 Summary

This part of the thesis has considered the question whether price regulated the market forces of supply and demand. Section 7.6.1 above has shown that in the LBA

[1314] Heltzer 1978: 122-123 and footnote 10 argues that as members of the *bnš mlk* were named in the same lists of other royal service professionals they could not have been in the same category as the group of auxiliary soldier/farmers that defended the kingdom in times of war. Heltzer 1996: 177 estimate for the size of the *bnš mlk* made up just over ⅓ of Ugarit's population were Royal dependents Heltzer 1996: 177 has estimated that the *bnš mlk* made up just over ⅓ of Ugarit's population and were Royal dependents. If Astour is correct and *bnš mlk* = merchants (*tamkars*) then "more ⅓ of the royal service-men in Ugarit were *tamkars*", a very unlikely situation (Heltzer 1978: 122).

[1315] Heltzer 1978: 128-129 citing the translation and commentary by Hoffner 1969: 36, 44 of two fragments of a Hittite text (KBo XII 42 and ABoT 49) with commentary and full references.

processes existed that could have enabled trading parties to place a value on goods allowing them to reach agreement for exchange purposes. This thesis proposes that the value of commodities such as copper and tin, over the long term must reflect the cost of production if economic collapse was to be avoided. Price did exist in the LBA but the textual evidence does not conclusively indicate that prices were dynamic and followed supply and demand, as they are today in modern capitalist markets. The combination of storage strategies to minimise the fluctuations in harvest yields, the ability to move staples around through trade or gift exchange, and the widespread use of gift exchange between ruling élites would have blunted the need for a pricing mechanisms that require the immediacy and response of modern formalist markets to the forces of supply and demand.

The silver balanced accounts widely used in the LBA Near East were laid out in such a manner that the profit on an exchange could have been determined but was not explicitly stated.[1316] Although other aspects of the transaction were calculated, profit was not highlighted as being the purpose of the accounting exercise. The silver balanced accounts suggest that the modern concept of profit was therefore different in the LBA. If we take these balanced accounts at face value their prime purpose was not to measure profit. This significantly weakens the proposition that the economy was formalist. In modern economics the central purpose of business enterprise is to maximise return to a level that the market can bear.

Proto-currency did exist in different forms and the silver shekel acted as a form of international standard of value. They both had attributes of money but the evidence as a whole indicates that a fully developed money economy did not exist. Metals may have been hoarded, metals were certainly used in exchange transactions, but this is some way from the concept of currency that can be used for universal payment of any form of goods and services.

The evidence of the activities, role, and status of the merchants above support Polanyi's assertion that merchants did not make their living from the differences between buying and selling. Their reward was land and social position.

[1316] For a detailed analysis of the role of silver in exchange transactions used in Mesopotamia see Snell 1982 and the Hittites see Floreano 2001: 209-235.

Overall the balance of evidence for this section comes down against a fully fledged formalist economy. There is insufficient evidence to suggest that prices were principally controlled by market forces. The limited textual evidence for variations in prices in the internal economy could easily be explained by famines, war, and/or state mismanagement. Gift exchange was still, in the period under study, an important part of interregional political relationships. It is unlikely that the value of copper and tin carried by the Ulu Burun boat could have been financed by private investors hoping to make a profitable return, when the risk of such an enterprise is taken into account.[1317] The sheer scale of the investment made in terms of the manpower required to produce the goods that were carried on the Ulu Burun boat make it more likely that the trading mission was state sponsored. The value of the cargo mutually would probably have been agreed between state élites.

## 7.6.4 Summary of key findings

| | Egypt | Cyprus |
|---|---|---|
| Manpower required to feed 100,000 population | 37,205 | 47,490 |
| Manpower required to clothe 100,000 population | 14,659 | 10,430 |
| Manpower available for added value production (average harvest) per 100,000 population | 13,320 | 7,264 |
| Total manpower (assuming population of Egypt 2.2 million and Cyprus 150,000) available for added value production (average harvest) per 100,000 population. | 293,040 | 10,896 |
| Ratio | 27 | 1 |
| Man-years to make 1000 kg copper | 827 | 433 |
| Weight of charcoal required kg to smelt copper and tin, refine copper, and alloy to make 1000 kg of bronze | 57,700 | 58,000 |
| Number of trees used to make this quantity of charcoal (Cyprus oak and Egypt acacia trees) | 13,453 | 9,212 |

[1317] There is some evidence from Ugaritic texts that sea loans (bottomry loans), similar to those in the Graeco-Roman period, may have possibly been used to minimise the risk of maritime trading missions in the LBA (Ziskind 1979: 134-137).

# Chapter 8: Conclusions

Chapters 3-5 of this thesis have quantified the manpower required to support the basic needs of Cyprus and Egypt in the LBA. The results show that, after excluding the élite and those too young or too old to work, in Egypt and Cyprus 80% and 89% of the adult population respectively were involved in the production of food, cloth, and shelter (basic needs). The workforce available for production of added-value goods for trade and for the conspicuous consumption of the élite, or for investment in state infrastructure projects, would have numbered 293,000 and 10,900 workers for Egypt and Cyprus respectively. As regards the scale of their added-value sectors, the economy of Egypt was 27 times greater in absolute terms than that of Cyprus. These results clearly show that the economies of Egypt and Cyprus in relation to their adult population were not as minimal in scale as proposed by Bücher, Weber, and Finley. From a world systems perspective, this data is certainly in accordance with Egypt's status as a core importer of commodity raw materials such as tin, wood, olive oil, and perhaps additional copper from periphery states. It is less clear, however, whether Cyprus was a periphery or a semi-periphery state. Textual evidence and scientific tests on the provenance of copper oxhide ingots around the Central and East Mediterranean confirm that Cyprus was a major exporter of copper, particularly in the thirteenth century B.C. This would make Cyprus, according to Wallerstein's theory, a periphery state, but Section 7.2.2 of Chapter 7 argues that, because the demand for copper was so great during the period 1400-1200 B.C., the cost of its production in manpower terms for Cyprus was half what it was at the Egyptian copper mines at Timna. This thesis has concluded that the unprecedented demand for copper and the low cost of copper production in Cyprus, combined with its strategic political and geographical position in the Mediterranean, made Cyprus a semi-periphery state. Comparing economies from a core-periphery viewpoint emphasises the critical dependence of all LBA regions in the Eastern Mediterranean on the supply of copper and tin, and highlights the strategies open to them to satisfy supply and demand.

The analyses in Chapters 3-6 are steady-state models which have assumed that the yield of the annual harvest was equal to the annual demand. Chapter 7, Section 7.2 took this one stage further by modelling the impact of famine and glut on the Cypriot and Egyptian economies during a hundred-year period. Statistics for harvest output were randomly varied to simulate the detrimental effects on the harvest of variable rainfall, in the case of Cyprus, and variations in flood levels, in the case of Egypt. Two other variables were also introduced to measure their impact; varying buffer stocks of grain in state granaries, and lowering the levels of rations from the state redistribution system. The results of this were dramatic, showing that the strength of an economy even as large as Egypt was vulnerable when famines occurred in two or more consecutive years, and they provided some interesting insights into the challenges and opportunities facing the LBA ruling elites. In the years of below-average harvests, the model shows that the combined strategies of a 10% buffer stock and a 20% reduction in calories provided the optimum levels to minimise severe malnutrition and starvation. A buffer stock of beyond 15% made the cost of building the requisite state granaries prohibitively expensive, and any cuts in rations of above 20% would have had over a number of years a severe impact on the working capacity of manual workers, and a detrimental effect on the gross reproduction rate of the females. Even with these ration cuts and the maintenance of a strategic buffer stock of grain, Egypt and Cyprus would not have been able to support all their added-value workforce for at least 32 and 40 years out of every hundred respectively.

Improvements in ship design and harbour facilities in the LBA make it unlikely that ships such as the Gelidonya and Ulu Burun wrecks were examples of isolated and infrequent trading expeditions. More likely they formed part of a large interregional marine transport system capable of carrying large quantities of inorganic and organic goods. Large volumes of grain were probably transported between those regions who had harvest gluts and those suffering from harvest failures. Section 7.2.3 has demonstrated that boats such as the Ulu Burun and Gelidonya wrecks were capable of transporting large quantities of grain in *pithoi*, which would have given protection from salt water spray. This thesis concludes that there was a strong possibility that grain was traded to alleviate shortfalls in regions facing famine. This balancing of grain requirements would have increased the overall scale of trade. As noted above, Cyprus was a low-cost producer of copper, but was constrained in production terms by its limited population of ca. 150,000-200,000. This thesis proposes that copper was traded for grain, therefore maximising the Cypriot workforce available for copper mining and smelting.

Archaeological and textual evidence of the scale of the metal trade, the wide distribution of Mycenaean, Cypriot, and Canaanite pottery, perfumed oils and exotic goods trade, and the possibility of large-scale trade in staples all point to the fact that during the period 1400-1150 B.C., the economies of the Eastern and Central Mediterranean were certainly neither minimal nor primitive. This thesis supports the case that an early form of globalisation was in progress at this time. However, this does not in itself mean that a formalist market was in operation. Substantive economies do not have to be limited in scale, and Polanyi's substantive model was based on trade administered through trading ports. Textual evidence clearly indicates that gift exchange with the obligation of reciprocity also had a part to play in interregional contact and exchange, but it could not in itself have satisfied the demand for metals and other commodities.

Many attributes for a market economy were already in place at this time. Egypt and Mesopotamia, and perhaps others, had fully-developed cost accounting systems. The metrology systems of the regions from the Central Mediterranean to Mesopotamia could be related to each other because they were based on rational mathematical progressions, which meant that a merchant from one region could mutually agree values with a merchant from another region. Silver balance accounting, used extensively across the Levant and Mesopotamia since the third millennium B.C., itemised the cost of producing materials, expenses incurred from production to sale, and the exchange price, and from this itemisation, profit could have been calculated. The surprising thing is that the merchants and their sponsors did not highlight the importance of profit, at least in textual evidence. This may be due to the fact that they were not focussed on the concept of profit as the sole objective of trading transactions which is normally associated with the rational interpretation of profit used in Neo-Classical profit and loss accounts. Kinship and reciprocal obligation may have been as important as, or more important than return on investment.

Egyptian and Mesopotamian state workers were paid by rank and profession in rations which were generally greater than what was required to feed themselves and their families. This thesis has proposed that this surplus created an informal internal market. The increased size of the Egyptian army in the Ramesside period and the increased numbers of diplomats stationed outside its borders in the New Kingdom increased the number of higher-paid officials. This encouraged the development of conspicuous consumption needs among this growing sub-elite socio-economic group. This demand for goods on the part of the sub-elite may have led to informal, 'piggy-backed' trade carried out by entrepreneurial sailors on the back of élite-administered trade.

Prices did change in the LBA, but it has not been possible from the evidence available to determine to what extent price regulated supply and demand, as the textual evidence for prices is too limited to conclusively link price to variations in supply. All the examples of price changes as discussed earlier in Section 6.5 could just as easily have been set by ruling élites, and the wide fluctuation in prices seen at the end of the LBA could have been the result of the élite reacting to sustained periods of glut and famine, or of state incompetence. It was probably only in periods of weakened government that private individuals had more opportunity to work outside the state system, as all the evidence leads to the conclusion that the LBA economy was embedded within the institutions of the state. Family kinship and responsibilities, minimal migration between socio-economic classes with the possible exception of the Army, the bureaucratic and hierarchical structure of LBA administration, and widespread evidence of state/temple-based redistribution, all point to the substantive nature of both Egyptian and Cypriot societies. This does not mean, however, that there were no embryonic formalist attributes. Demand for 'foreign' products, not only from the ruling élite but also from the growing ranks of the sub-élite, was increasing because of interregional trade. A number of indicators suggest that the substantive economy was evolving. Proto-currencies, value comparators, metrology systems, proto-profit and loss statements, and cost accounting systems that had the potential to develop beyond mere planning and control and provide a true cost-allocation methodology were all in evolution during this period. The existence of these indicators shows a more responsive and rational attitude to satisfying the needs of the economy, and when linked to improved methods of sea transport, opened new possibilities for trade and economic development.

The use of a quantitative approach on the study of the LBA economy has provided a new perspective on the substantive-formalist debate. This thesis has shown that it is possible to make estimates of the cost of ancient production processes in terms of the resources required, using the *chaîne opératoire* methodology together with evidence from archaeological and textual records, archaeo-scientific methods, and appropriate experimental and ethno-archaeological evidence. This thesis demonstrates that the gross domestic product of the LBA economy can through modelling be related directly to the cost of production, in terms of the manpower required to support the major economic sectors that made up the economy: agriculture, cloth, building, bronze, and added-value manufacturing. Examining the economy from the perspective of satisfying unlimited needs with finite manpower resources, that has to be supported by the harvest surplus, highlights the issues facing ruling LBA élites in terms of the prioritisation of resources.

Although the input parameters of the quantitative model are LBA-specific, the model is generic and can be adapted to any period in antiquity where any non-agrarian activity has to be supported directly or indirectly by the harvest surplus. Future research into the manpower requirements necessary to produce glass, gold, silver and fine ware goods would complement this study. While the substantive-formalist debate remains unresolved, this quantitative study has provided the building blocks for a 'top-down' macro-view of the LBA economy that complements and enhances previous scholarship of the incomplete evidence from archaeological and textual records.

From an overall perspective, this thesis concludes that the LBA economy was essentially substantive in nature. However, if economic recession had not intervened ca. 1200-1150 B.C. (possibly due to the Sea Peoples and/or climate change), a fully-fledged formalist market might have continued to develop in the Eastern and Central Mediterranean.

# Appendix 1: Provenance of LBA copper ores

## Use of Lead Isotope Analysis to determine the provenance of ores

Lead isotope analysis (hereafter LIA) measures the stable isotopes of lead using a mass spectrometer in order to characterise particular ores or artefacts and associate them with known lead sources. The four common isotopes measured are $Pb^{206}$, $Pb^{207}$, $Pb^{208}$, and $Pb^{204}$. The key benefit in using LIA for provenance analysis is the fact the Lead Isotope Ratios do not change during any metallurgical process. The ratios remain stable irrespective of the temperature in the smelting furnace, the reducing-oxidising conditions under which the metal was smelted, or even the number of times it was subsequently re-melted.

LIA testing was the method of choice used by the Oxford Isotrace Laboratory under the Directorship of Gale, assisted by Stos-Gale, to determine the provenance of ores and artefacts, but it is a controversial methodology. The main objection made by LIA sceptics is the issue of recycling. This thesis will not review in detail the pros and cons of Lead Isotope Analysis, but takes the position that, provided LIA results are linked to other evidence such as trace element analysis and to the complete archaeo-socio-economic context, it provides a valuable tool that has contributed much to our understanding of the provenance of copper artefacts and the LBA metals trade. Even if the most pessimistic view is taken regarding the validity of LIA, the work of the Oxford Isotrace laboratory has clearly demonstrated that the method can show clearly that the LIA of an isotope is consistent with that of an ore body, and whether an artefact is made from an ore of a particular area. This is important for the purposes of this thesis (as is demonstrated in Section 5.4), as the distances involved in transporting men, supplies and workers contribute significantly to total production costs. For example, in the case of Timna, where long distances had to be covered, transporting tin and copper to the refining centre at Piramesses accounted for 17.5% of the total cost.

### Provenance of the copper ores that produced the copper ingots found on the Ulu Burun

LIA evidence has been used to identify the possible provenance of the copper ingots on the Ulu Burun wreck. The LIA results for 187 ores taken from 24 mining districts within the pillow lavas of the Troodos Mountains show that ores can be geologically and geographically differentiated. LIA and trace element analyses of gold and silver in the oxhide and flat-convex copper ingots from the Ulu Burun and Gelidonya wrecks indicate they were probably smelted from copper sulphide ores mined in the Troodos Mountains of north-west Cyprus. The relatively tight clustering of LIA ratios indicate that the most probable source of the ore that produced the bulk of the copper ingots on the Ulu Burun wreck (1318± 21 B.C.) was a single source or a number of mines close together, probably one ore or combinations of ores from the

Phoenix, Apliki and Skouriotissa mines (Figure 5.14) for the locations of the mines). The LIA ratios for Cypriot ores and ingots from the Cypriot mines, as of 2005, found in the Ulu Burun and Gelidonya wrecks are published in detail by N.H. Gale and Z.A. Stos-Gale. The copper ores of the Gelidonya wreck (ca. 1250 B.C.) probably came from Apliki mine, but could have been mixed with those from the nearby Mavrovouni or Skouriotissa mines. The LIA results for the Ulu Burun also show that at least part of the copper had been processed in Enkomi and Kalavassos Ayios Dhimitrios in Cyprus, as it has a similar LIA signature to that of copper prills found in LBA slag at these sites.

### Metallographic studies of the Ulu Burun copper ingots

Hauptman *et al* drilled core samples from both the oxhide and bun-shaped ingots, etched and mounted them for examination under a Zeiss Axiophot microscope. They show an extraordinarily high porosity, of up to 20% in volume. This may have been caused by the effervescence of oxygen, carbon monoxide, and carbon dioxide created when water came into contact with carbon and sulphur dioxide produced after the oxidation of the sulphur in the ore. The evidence of this effervescence in the ingots, couples with sulphur and sulphide residues in slag inclusions in the ingots, suggests that the sulphide ores were used from Cyprus.

## Provenance of tin used in the LBA Eastern Mediterranean

Natural tin is a rare commodity and there were only two sources of tin ore available to LBA prospectors; alluvial placer tin in the form of nuggets of ore (SnO2) deposited in ancient river beds, and tin obtained from veins of cassiterite within a matrix of quarts and granite.

### Possible sources of tin in the LBA

Egypt has its own placer cassiterite ore deposits in the Eastern Desert at Igla, Aby Dabbab, Nuweib, el Muelli, and Homr Akarem. Although some ore is mined today, there is no evidence to suggest it was exploited in the Pharaonic period. Cyprus, Crete, mainland Greece, northern Syria and southern Anatolia have negligible deposits or none at all. The tin mines at Goltepe in the Taurus Mountains of central Anatolia may have supplied some of the requirements for tin in the EBA Eastern Mediterranean. Some scholars suggest that by the end of the EBA Anatolia itself was not self-sufficient in tin and had to import the metal from outside its borders. Gale suggests there may have been a link between the tin trade and lapis lazuli exports from Afghanistan, but Muhly disagrees, arguing that there is no evidence to link the bulk metals trade and the luxury trade. From this location tin and copper would have been shipped to other coastal hubs in the Eastern Mediterranean, and possibly to the Central Mediterranean as well.

With the unstable political situation in Afghanistan since the Second World War, significant archaeological work into prehistoric mining has been limited. A geological survey carried out by the Afghanistan and US Governments has recently identified more than 100 mineral deposits and occurrences of tin, to the south and west of Kabul and associated with magmatism of the Cretaceous to Oligocene geological periods (Figure 5.15). Tin deposits have been found in the Sarkar Valley of western Afghanistan, and these are thought to have been exploited by the peoples who built Bronze Age mounds in the region. The excavation work of Cierny and Weisgerber has shown that the mines in Uzbekistan, Tajikistan, and East Kazakhstan (central Asia) were mined in the LBA/EIA period. Texts show that Mesopotamian merchants traded with Afghanistan for lapis lazuli in the MBA. We also know from textual sources that Mesopotamian merchants traded tin with Anatolia and possibly Ugarit for silver and gold in return. However, Mesopotamian textual evidence is related to tin within the state and its trade with Anatolia, and not to its sources. The mines of central Asia, nevertheless, still provide the best hope of answering the riddle of the supply of tin in the LBA, and on this basis it is assumed for the purposes of this thesis that Central Asia was the source of tin for the Eastern and Central Mediterranean.

**Provenance of the ores that made the tin ingots found on the Ulu Burun wreck**

The tin ingots on the Ulu Burun were examined in situ and found to be very pure. Approximately 1,000 kg of tin has been recovered from the Ulu Burun wreck, but unfortunately most of the ingots have undergone a complex process in the sea that has converted them from metallic tin to grey tin, with the consistency of toothpaste. Despite this crystalline change, the Ulu Burun diving team successfully lifted all of the tin and remarkably some of the ingots have retained their original oxhide, bun and slab shapes. LIA isotope testing and trace element analysis have failed to establish a conclusive link between the tin ingots and their ores. Stos-Gale states that the provenance of tin ores in antiquity remains one of the most significant unsolved problems of the past two decades of research. On the balance of the evidence above, with probable tin trade links between central Asia and the Eastern Mediterranean and the archaeological evidence of tin production in central Asia, this thesis has concluded that the provenance of the Ulu Burun tin ingots was in central Asia.

# Metallurgical glossary

Annealing: Heating the metal object to a suitable temperature before allowing it to slowly cool. In this process, the grains of the metal are re-aligned and grow larger. This relieves stresses built up when artefacts are hammered or rolled into shape.

**Alloying**: Deliberate chemical combination of two or more metals.

**Azurite:** Azurite is blue copper carbonate ore ($Cu(OH)_2 . 2CuCO_3$).

**Beneficiation:** The process where extracted ore from mining is broken down by hammering or grinding into smaller particles that can be separated into pure ore and gangue, the former suitable for further processing and the latter rejected.

**Black copper:** The name given to impure copper following smelting.

**Bloomery Iron:** The first product of smelting iron ore in charcoal. It is relatively pure iron with only small amounts of slag inclusions.

**Calorific value:** Amount of heat produced by the complete combustion of a unit weight of fuel. Calorific value is usually expressed in kcals/kg for solid fuels or $MJ/m^3$ for gas.

**Cassiterite:** Cassiterite is the main ore used to produce sin ($SnO_2$). It is usually yellow, brown, or black in colour, depending on the amount of iron within the ore.

**Chalcocite:** Chalcocite is a black or gray lustrous copper sulphide ore ($Cu_2S$)

**Chalcopyrite:** Chalcopyrite is the most common naturally-occurring copper sulphide ore and is yellow in colour ($CuFeS_2$).

**Copper matte:** Copper matte is the product of roasting dry concentrated sulphide ores to drive off excess sulphur prior to smelting.

**Crysocolla:** Crysocolla is a copper silicate ore ($CuSiO_3 . 2H_2O$).

**Cuprite:** A natural red secondary ore of copper, essentially cuprous oxide $Cu_2O$, that forms as a result of weathering.

**Endothermic chemical reaction:** A reaction that absorbs heat from its surrounding as the reaction proceeds.

**Exothermic chemical reaction:** A reaction that produces heat as the reaction proceeds.

**Flux:** A substance added in the smelting process to combine with impurities to form a molten mixture. This mixture, being lighter than the smelted metal, enables it to be easily removed from the furnace of crucible.

**Gas porosities:** Pits, holes, and blisters found on the surface of copper ingots caused by the escape of gasses in the cooling process.

**Gangue:** The valueless rock component of metal ores.

**Gossan:** A weathered iron-rich product overlying exposed sulphide deposit mix, formed by the oxidation of the sulphides of copper by the percolation of rainwater through the veins of minerals.

**Grade:** The concentration by weight of a metal in a mineral deposit or ore.

**HV (Vickers Pyramid Number):** The Vickers Diamond Pyramid hardness number HV is the applied load (kg) divided by the surface area of the indentation (mm2), and is a measure of the surface hardness of a metal. A Vickers hardness tester is used to measure the plastic deformation of the surface under a standard force using a industrial-standard shaped diamond indenter.

**Hydrothermal:** The action of the passage of hot water through rocks. Important in mineral exploration because hot, often superheated, water can dissolve and carry metals, and later precipitate them to form mineral deposits.

**Isotope:** A characteristic of an element that differentiates from other isotopes of the same metal by the number of neutrons in the nucleus.

**LIA (Lead Isotope Analysis):** The measurement of the stable isotopes of lead using a mass spectrometer in order to characterize particular ores or artefacts and associate them with known lead sources. The four common isotopes measured are $Pb^{206}$, $Pb^{207}$, $Pb^{208}$, and $Pb^{204}$.

**Liquidus temperature:** The temperature at which the molten flux and gangue become a low viscous fluid.

**Lode deposit:** A discrete mineral deposit found within a consolidated host rock (see placer deposit below).

**Magmatism:** The formation of igneous rock from magma

**Malachite:** Malachite is a green copper carbonate ore ($Cu(OH)_2 \cdot CuCO_3$).

**Matte:** An unfinished metallic product of copper and iron formed in the smelting process of copper sulphide ores and made up of copper, sulphur, and iron.

**Melt:** The liquid phase of smelted metal and molten slag. The slag, being lighter than the molten metal, floats to the top and can be removed through a tap hole in the side of the furnace.

**Petrography:** The study of rocks by means of microscopic examination of thin sections using a polarisation microscope.

**Petrology:** The geological and chemical study of rocks

**pH:** A measure of alkalinity or acidity of a solution. A neutral solution would have a measure of 7, and a measure of 1 would be the strongest acid solution and 15 the strongest alkaline solution.

**Pillow lava:** Lava that forms from an underwater eruption and is characterised by pillow-shaped masses.

**Placer deposit:** A placer or stream deposit is formed when the original deposit of ore has been eroded, carried away by water and laid down as an alluvial deposit, most frequently in the sands and gravels of river valleys.

**ppm:** Parts per million by weight.

**Prills:** Prills are small inclusions of copper trapped in the slag formed in the smelting process.

**Pyrite:** An iron disulphide mineral ($FeS_2$), sometimes called “fools gold” owing to its brass-yellow colour.

**Refining:** Removes any remaining gangue and other impurities in smelted black copper. In antiquity this was carried out by melting the black copper in a reductive charcoal fire, which oxidised the impurities.

**Refractory:** A refractory material is one that can withstand very high temperatures without changes to its basic physical or chemical structure.

**Reduction:** A reduction process occurs when oxygen is absent and elements are reduced by gaining electrons. Under anaerobic conditions (no dissolved oxygen present), sulphur ores are reduced to produce hydrogen sulphide ($H_2S$).

**Roasting:** The process of heating copper sulphide and chalcopyrite ores to produce and remove sulphur dioxide from the ore.

**Sintering:** A solid-state process where bonds are developed in high-temperature conditions between grains of materials that have been brought into contact.

**Shear zone:** A linear zone of fracturing and tearing of the rocks which can provide passage for hydrothermal mineralising fluids.

**Slag:** A furnace product formed in the smelting process by the fusion of waste material (gangue) with flux formed after the separation of the metal phase. Tap slag is the free-flowing liquid state in the smelting process. The term furnace slag, used by archaeologists, is a viscous form of slag where there has been an incomplete separation of gangue and metal.

**Smelting:** A pyrotechnology where metals are separated from the other components of its ore. The process normally includes a liquid metal phase followed by a liquid slag phase.

**Specific heat:** The ratio of thermal energy required to raise the temperature of a body by 1°C to the thermal energy required to raise an equal mass of water by 1°C.

**Tailings:** Gangue left after the beneficiation process.

**Tap a furnace:** The removal of slag or metal from a furnace through a tap hole in the side of a furnace.

**Tonne:** A metric tonne of 1,000 kilograms

**Tuyère:** An air tube, made of clay, connecting the bellows and the furnace.

**Viscosity:** The material property that measures a fluid's resistance to flowing.

**Vitrification:** The change in the fabric of the ceramic through the action of heat in a reducing atmosphere.

**Work hardening:** The process where metal is made harder by rolling or hammering, owing to a reduction of the size of grains in the metal's polycrystalline material.

# Chemical glossary

**As:** Arsenic
**Au:** Gold
**C:** Carbon
**CO:** Carbon monoxide
**$CO_2$:** Carbon dioxide
**Cu:** Copper
**$CuO_2$:** Cuprous oxide
**Fe:** Iron
**FeS:** Iron sulphide
**$H_2SO_4$:** Sulphuric acid
**Mn:** Manganese
**Pb**: lead
**$O_2$**: Oxygen
**S:** Sulphur
**Si:** Silica
**Sn:** Tin
**$SO_2$**: Sulphur dioxide

# The Nature and Scale of the Late Bronze Age Economy in the Eastern Mediterranean for the Period 1400-1175 B.C.

**Volume 2 of 2 Volumes**

**Keith Padgham**

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Submitted to the University of Wales in fulfilment of the requirements for the Degree of Doctor of Philosophy.

Swansea University 2008

# Chapter 1 Figures: Introduction

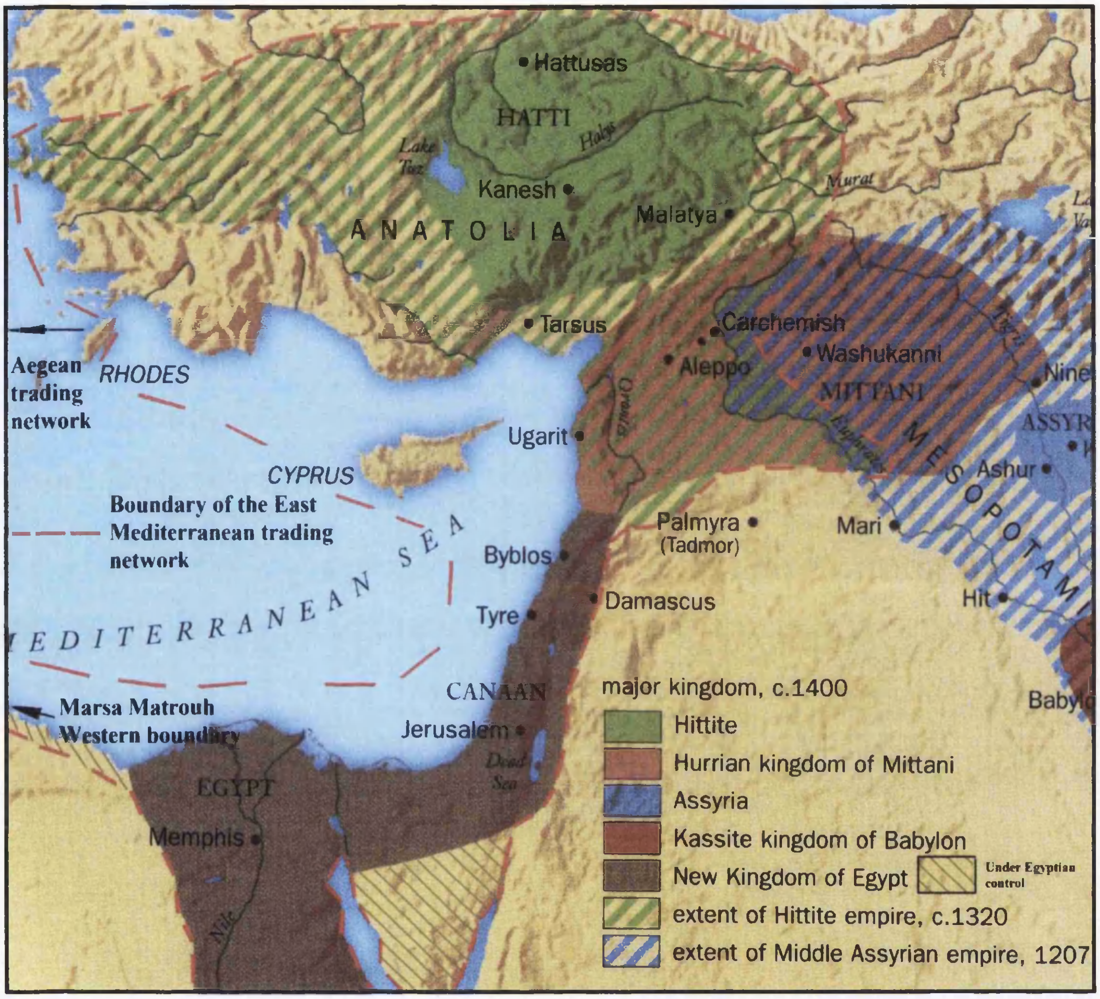



**Figure 1.1: The Eastern Mediterranean as defined for this study to be within the boundary of Egypt, Northern and Southern Levant, Ugarit, Anatolia, and Cyprus. Rhodes is considered to be a gateway link between the Aegean and Eastern Mediterranean trading networks.**
Adapted from Farrington 2005: 11.

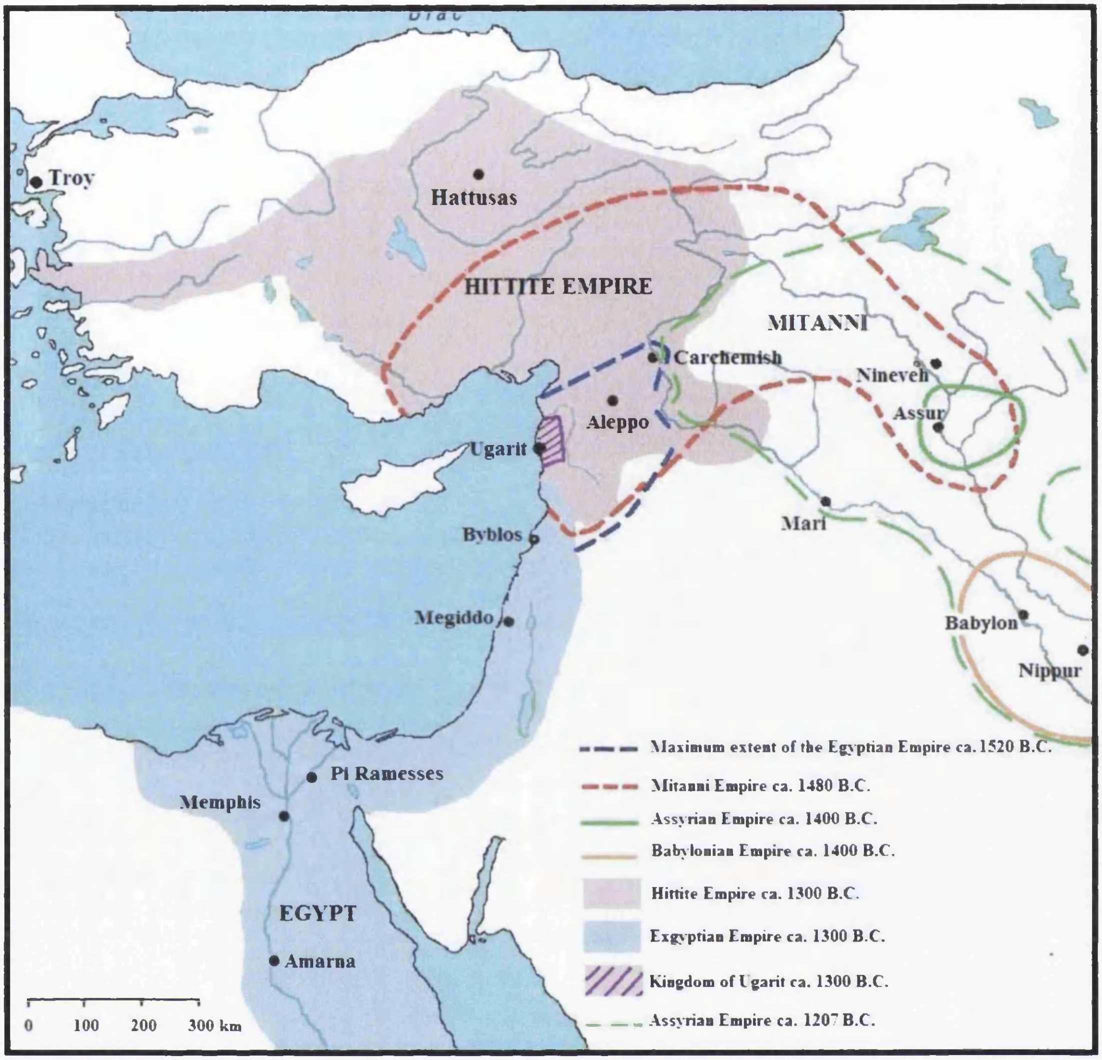



**Figure 1.2. Political map of the Eastern Mediterranean in the LBA, showing the strategic position of Ugarit between the Hittite and Egyptian empires, the diminishing power of the Mitanni, and the rising power of Assyria to the east.**
Adapted from Hunt 2004: 80-81.

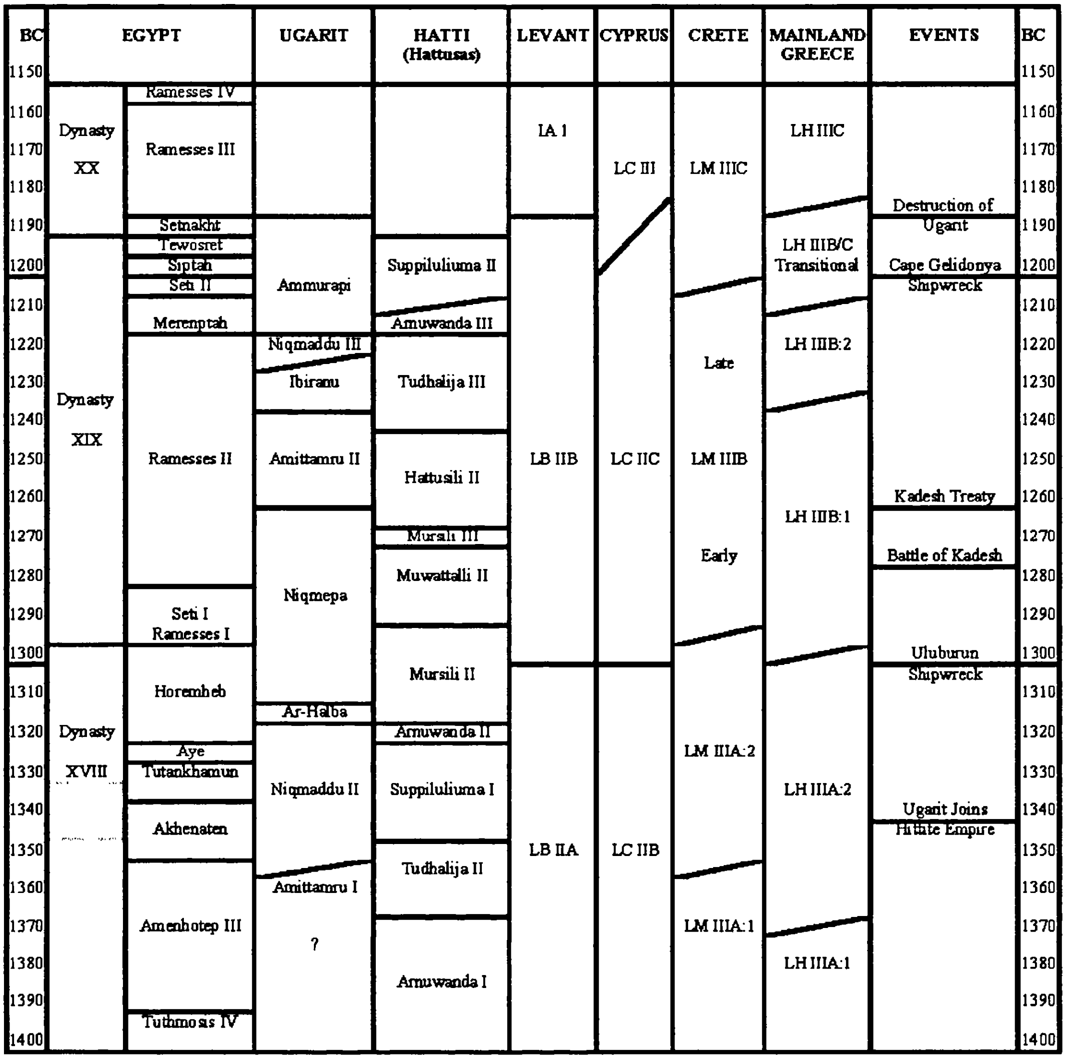



**Figure 1.3: Relative chronologies for the LBA 1400-1150 B.C. for the Eastern Mediterranean and the Aegean.**

After Bell 2005: 12, Figure 1.

# Chapter 3 Figures: Agriculture

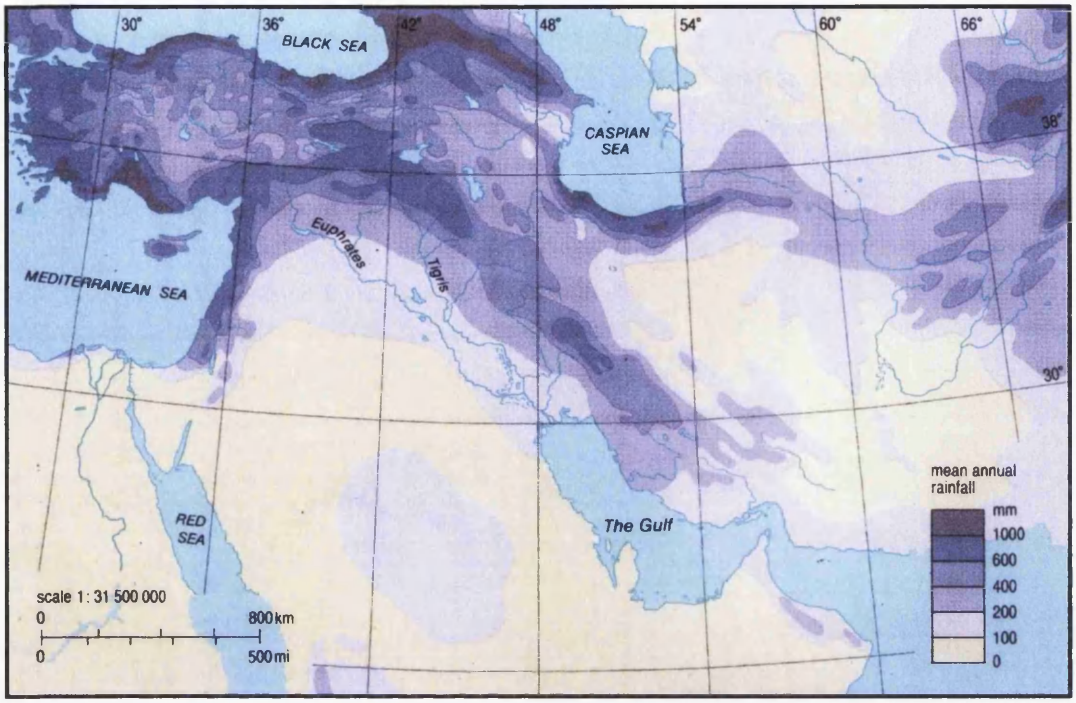



**Figure 3.1: Rainfall in the Eastern Mediterranean**
After Roaf 1990: 22.

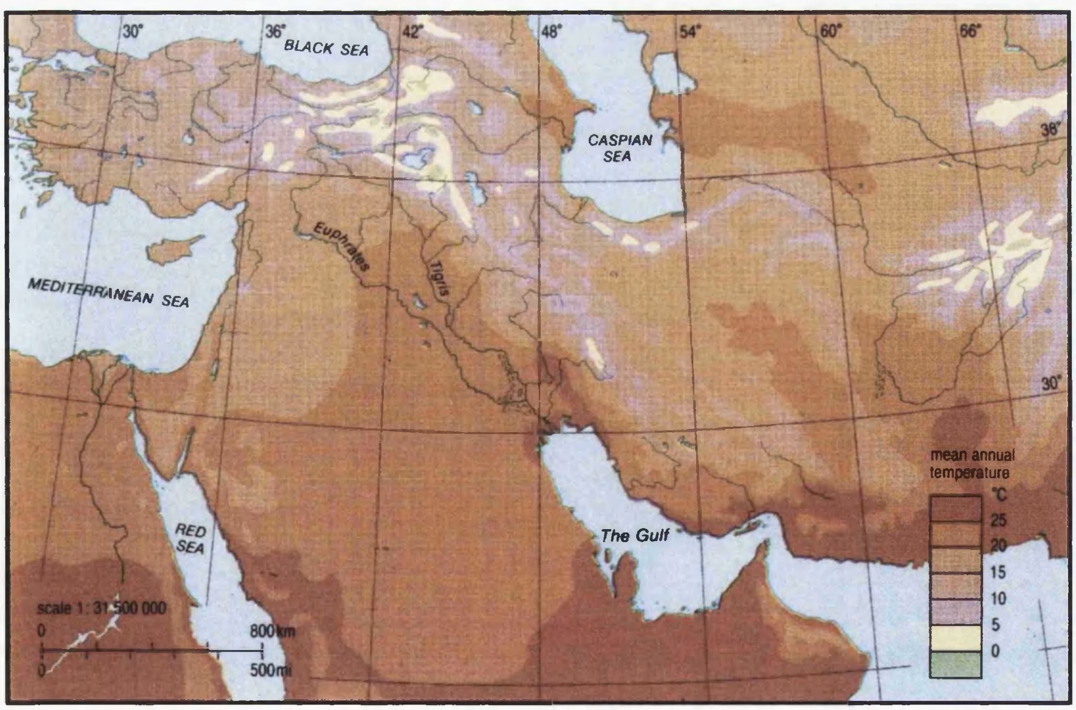



**Figure 3.2: Temperature profile of the Eastern Mediterranean**
After Roaf 1990: 23.

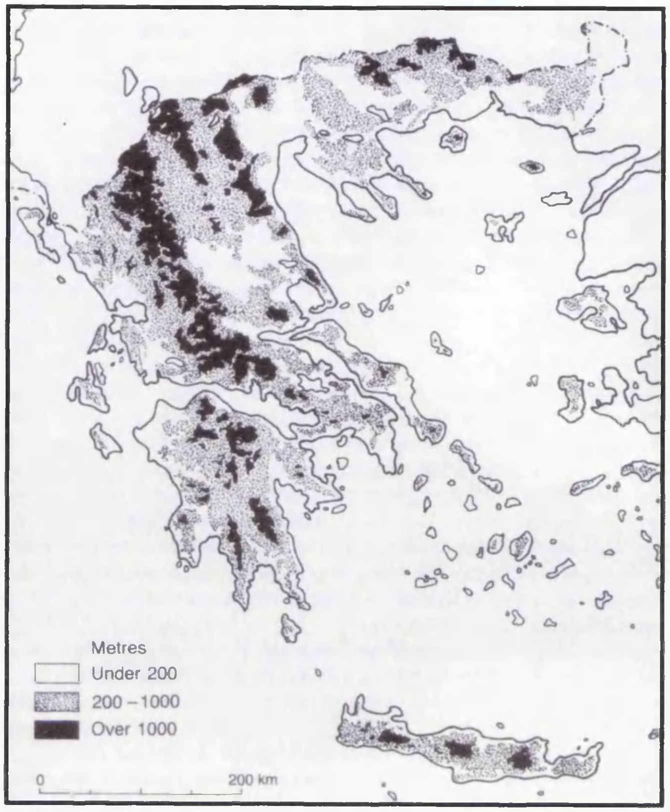



**Figure 3.3: Topography of the Aegean**
After Isager 1992: 12, figure 1.1.

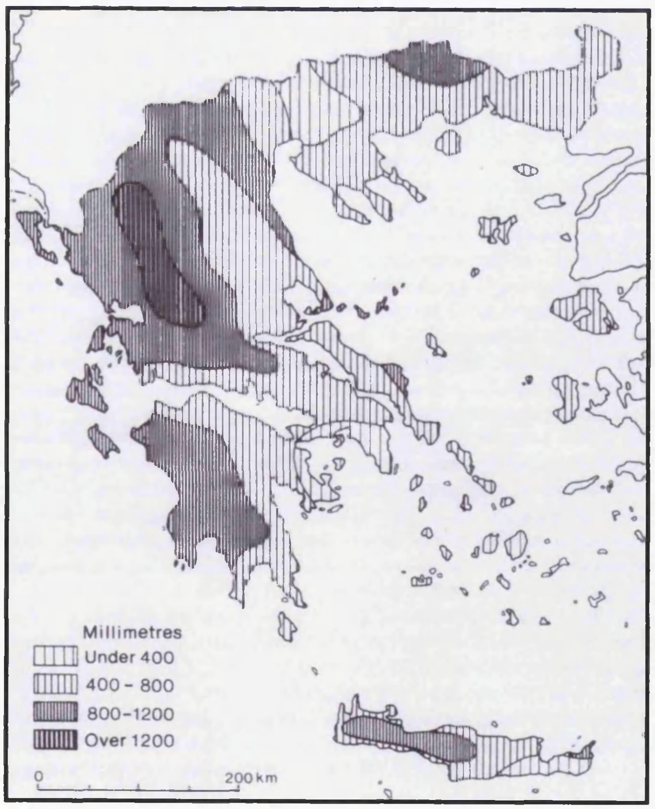
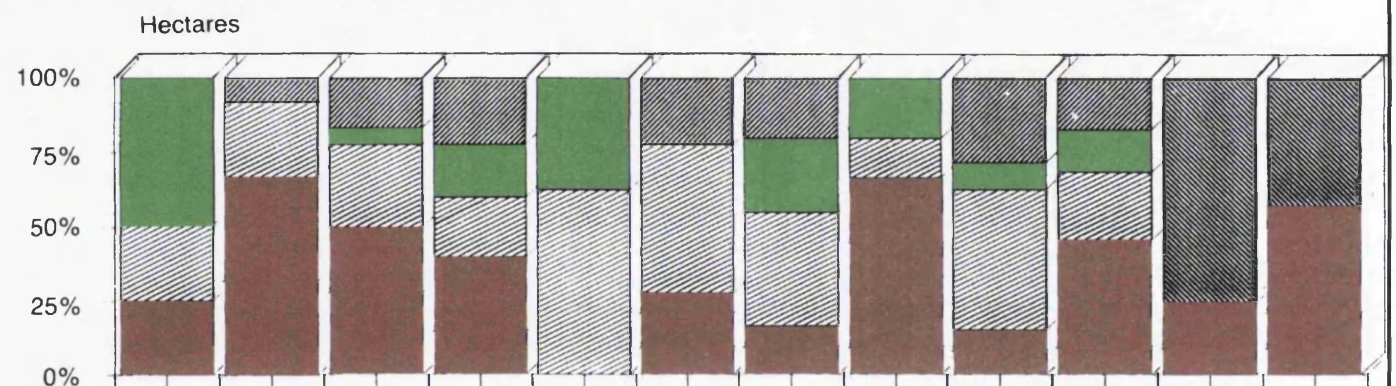



**Figure 3.4: Annual rainfall in the Aegean**
After Isager 1992: 12, figure 1.1.


**Figure 3.5: Ethnographic evidence of the agricultural cycle in Israel and the epigraphic evidence from the Gezer Tablet**
Adapted from combining the tables from Borowski 1987: Tables 1-3.




| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fallow | 1.0 | 0.1 | 0.3 | 0.0 | 0.0 | 0.4 | 1.2 | 0.0 | 18.4 | 3 | 0.0 | 0.0 |
| Cash crops | 3.5 | 0.0 | 0.1 | 0.8 | 0.6 | 0.9 | 1.5 | 1.5 | 6.0 | 2.5 | 11.3 | 3 |
| Fodder | 1.8 | 0.3 | 0.5 | 0.9 | 1.0 | 0.0 | 2.3 | 1.0 | 31 | 4.0 | 0.0 | 0.0 |
| Wheat | 1.8 | 0.8 | 0.9 | 1.8 | 0.0 | 0.5 | 1.0 | 5.0 | 10 | 8.0 | 3.7 | 4.0 |

Village

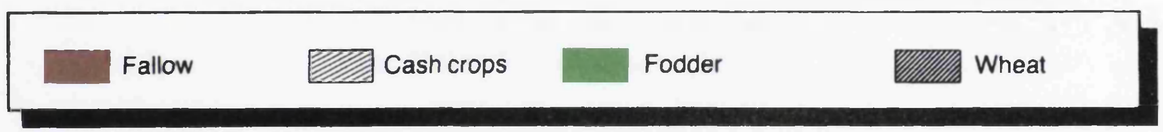



**Figure 3.6: Distribution of crops in Thessalian Villages showing regular fallowing patterns.**
Adapted from Gallant 1991: 55, figure 3.2.

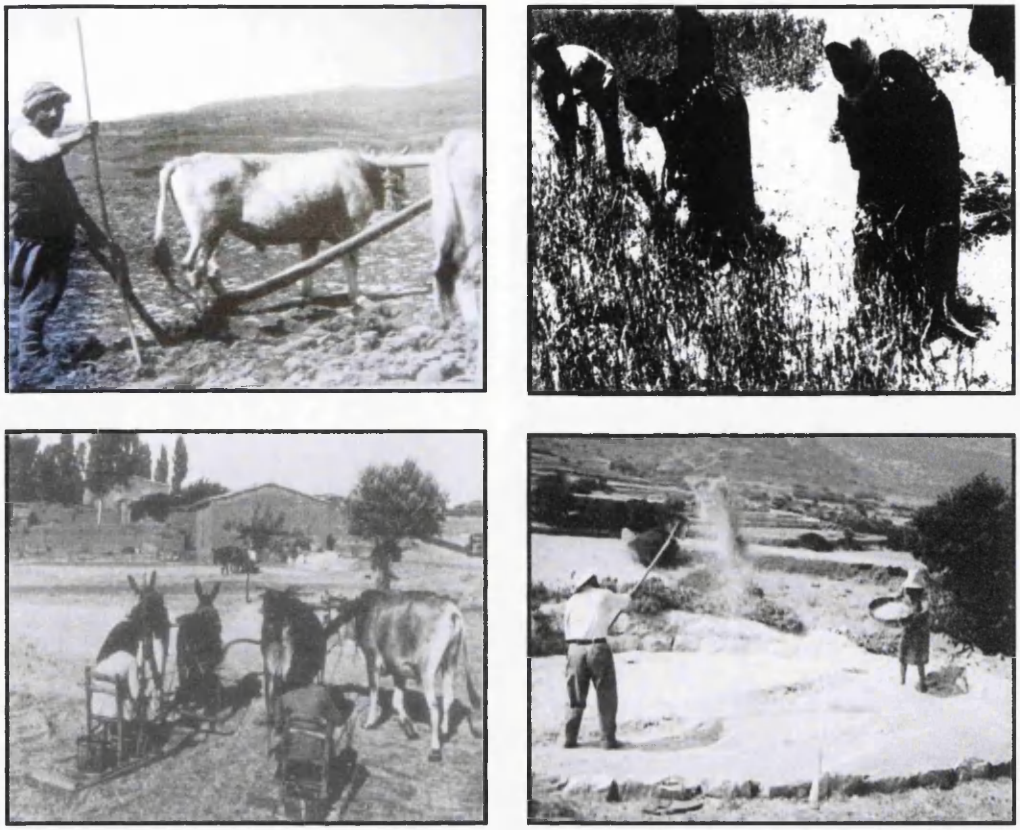


**Figure 3.7: Traditional farming practices common up to the 1960's and early 1970's. Top, a pair of oxen ploughing using a wooden ard share in Bulgaria and traditional sickle-reaping of wheat in 1974 Central Turkey. Bottom threshing sledges in Neo Chorio, Cyprus and winnowing in Greek Island of Amorgos.**

After Whittaker 2000: 64 (top left), Halstead and Jones 1989: 56, Plate 1 (top right), Skakun 1999: 201, figure 21.6 (bottom left), and Hillman and Davies 1999: 80, Figure 10.6 (bottom right).

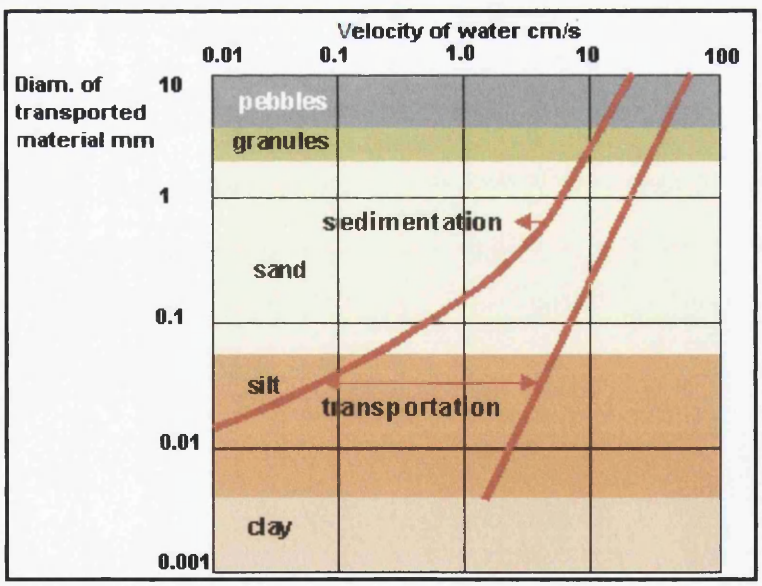



**Figure 3.8: Relation ship of water velocity and size of material carried.**

Adapted from Anthoni 2000: 9.

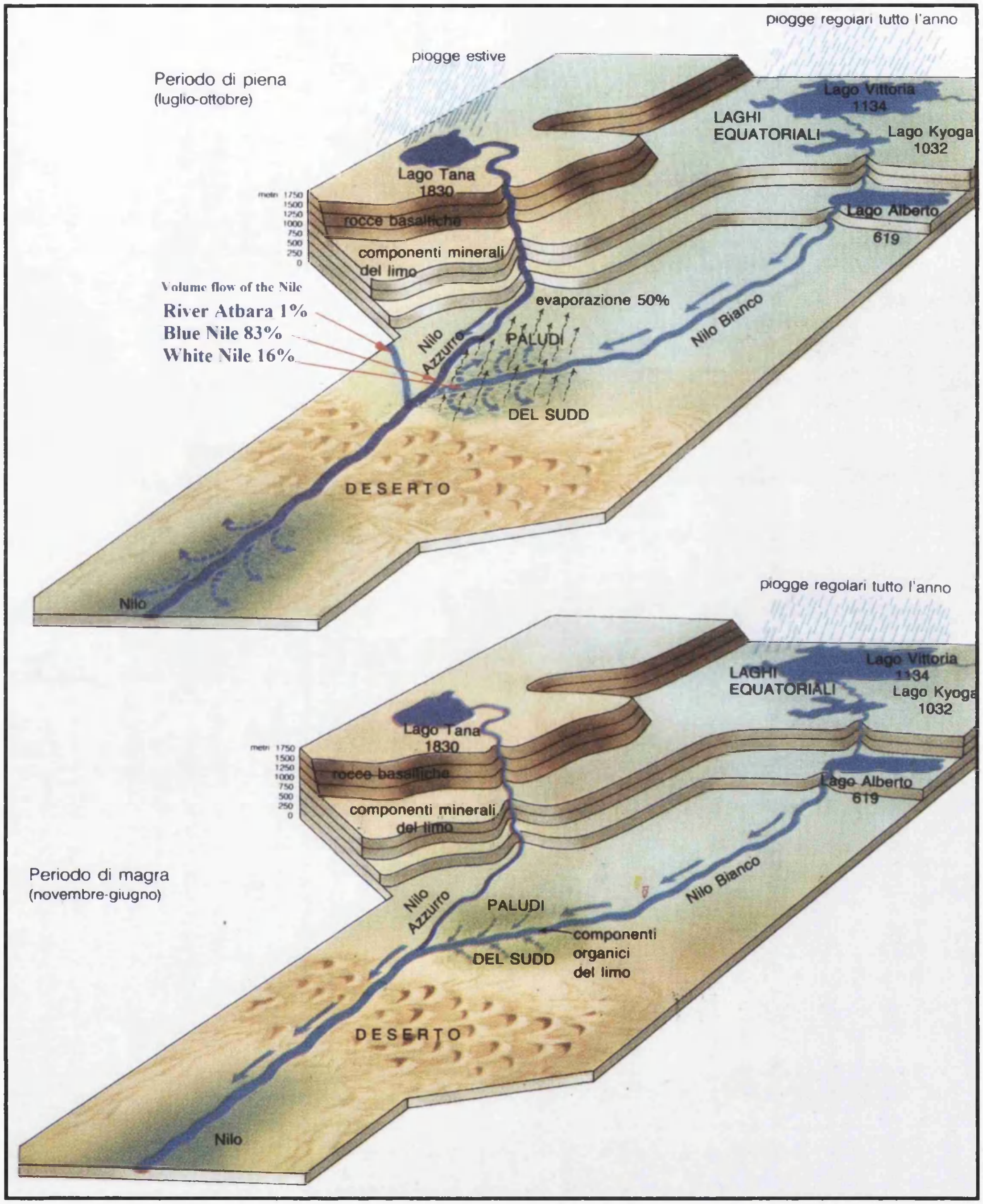



**Figure 3.9: Contribution to the flow of the Egyptian Nile from the Blue Nile, White Nile, and River Atbara.**

Adapted from Donadoni *et al* 1993: 103.

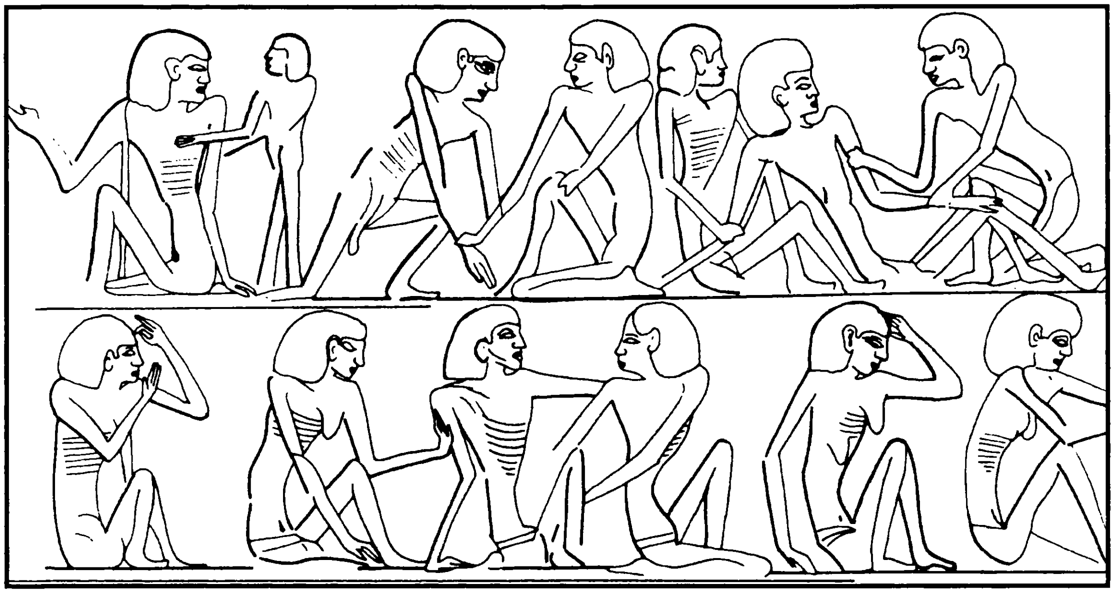


**Figure 3.10: Famine scenes from the causeway at the mortuary temple of Wenis at Saqqara (Dynasty IV).**
After Darby 1977: 68 fig 2.7a.

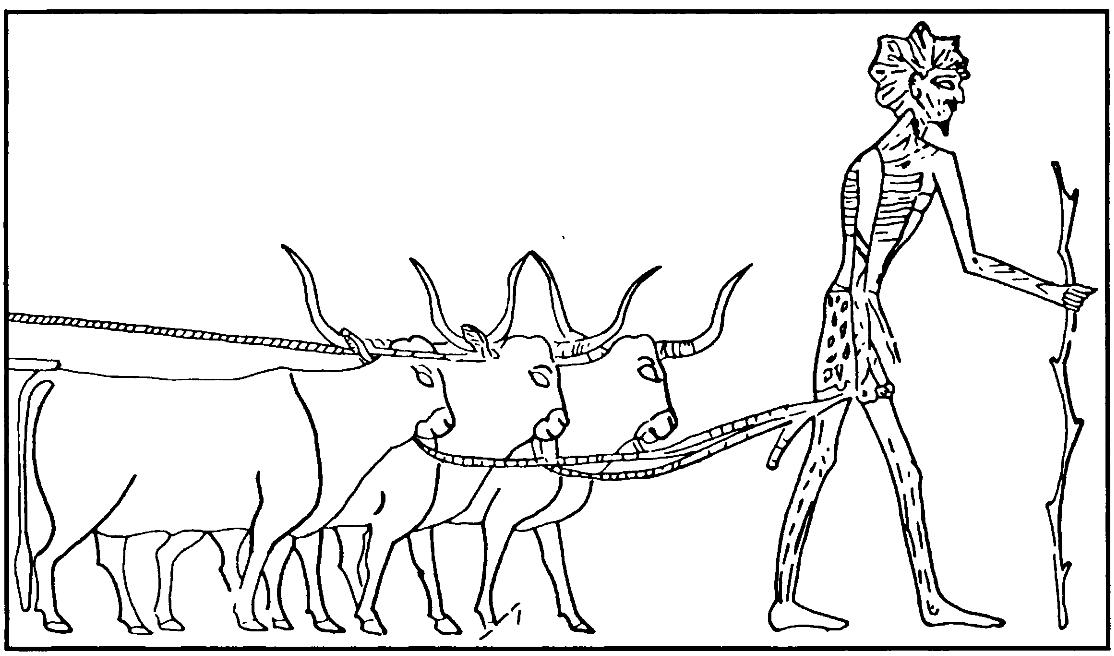


**Figure 3.11: Tomb Ukh-hotep at Meir showing an emaciated stockman (Meir B3, Dynasty XII, reign of Senwosret I).**
After Darby: 112, fig 3.16.

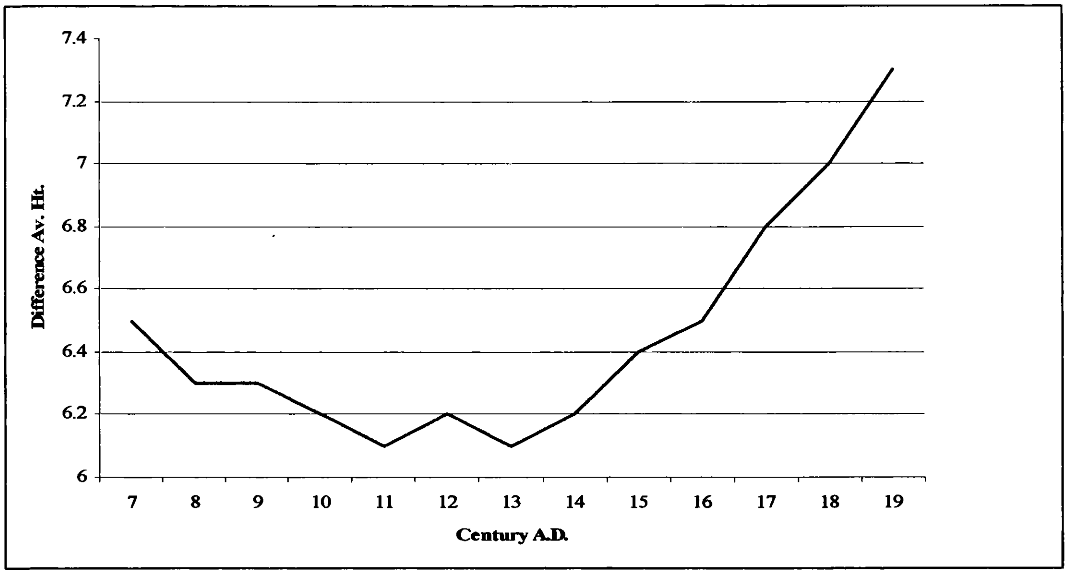



**Figure 3.12: Averages of the differences in maximum flood and low water levels of the inundation in metres per century measured on Roda Island near Cairo.**
Tabular data taken from Willcox and Kemeid 1904: 50.

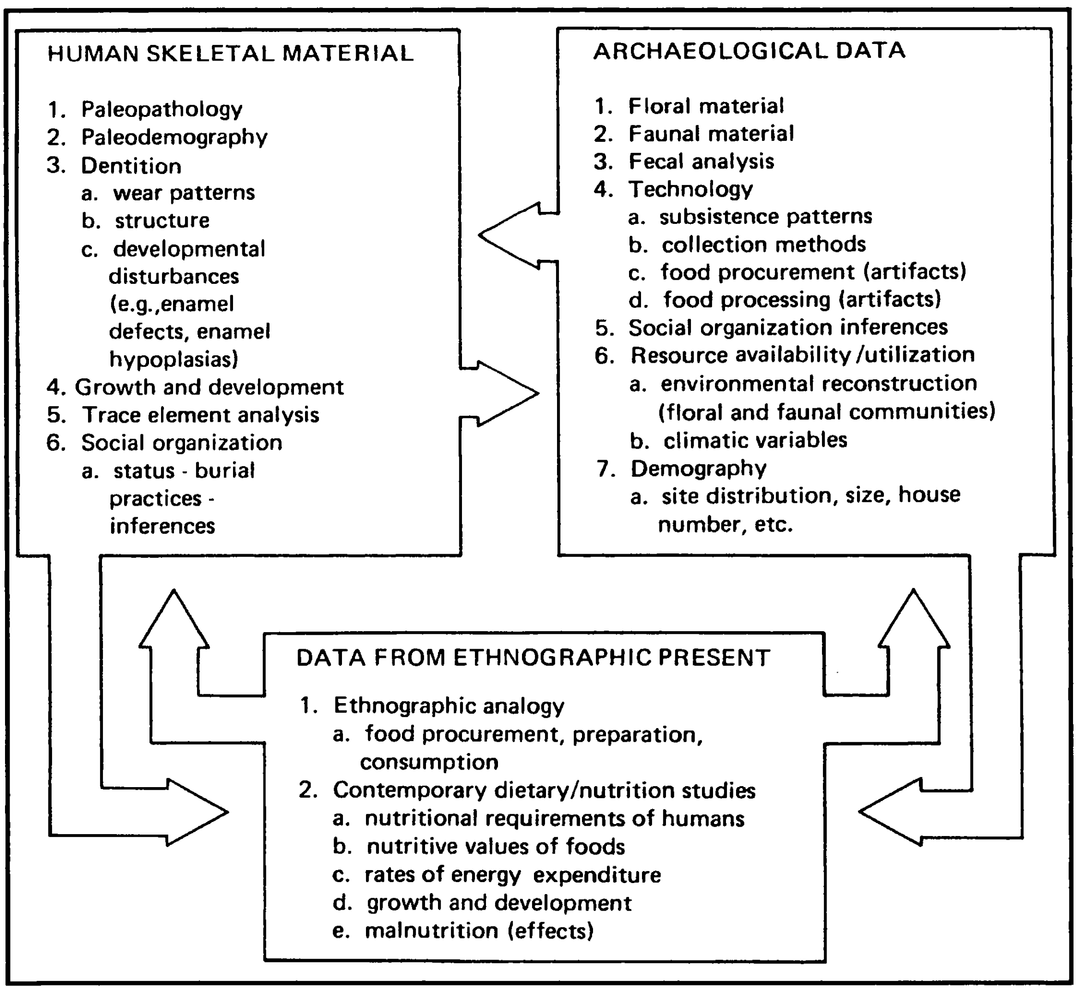



**Figure 3.13: How data derived from human skeletal remains, plant and animal remains and environmental variables linked to cultural data from the textual and archaeological record lead to our understanding of the ancient diet.**
After Gilbert and Mielke 1985: xiii, figure 1.

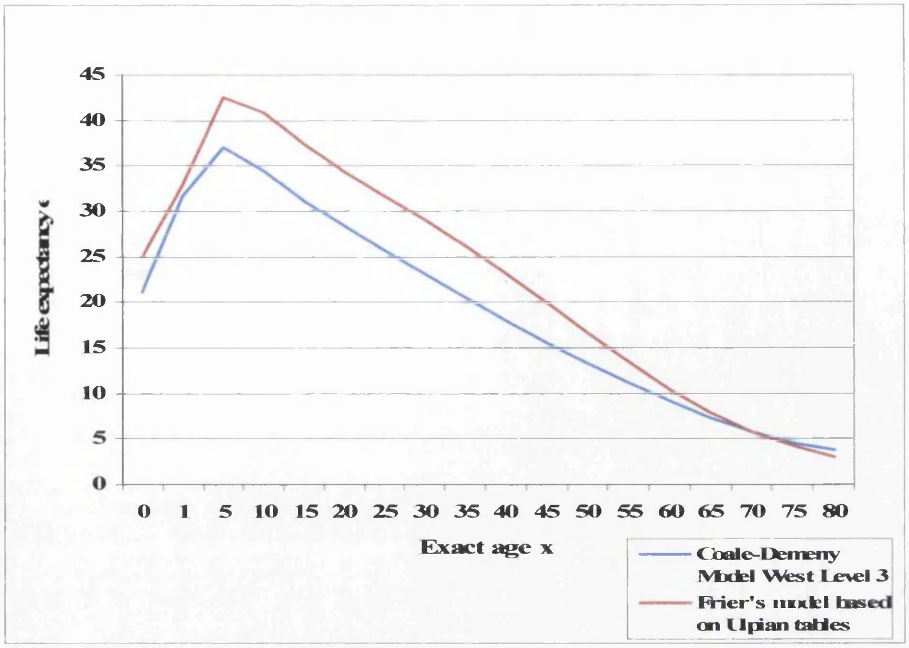



**Figure 3.14: Average life expectancy using Frier's and Coale-Demeny Model West level 3 life tables.**
Adapted from Frier 1982: Table 5 and Parkin 1992: 148, Table 10.

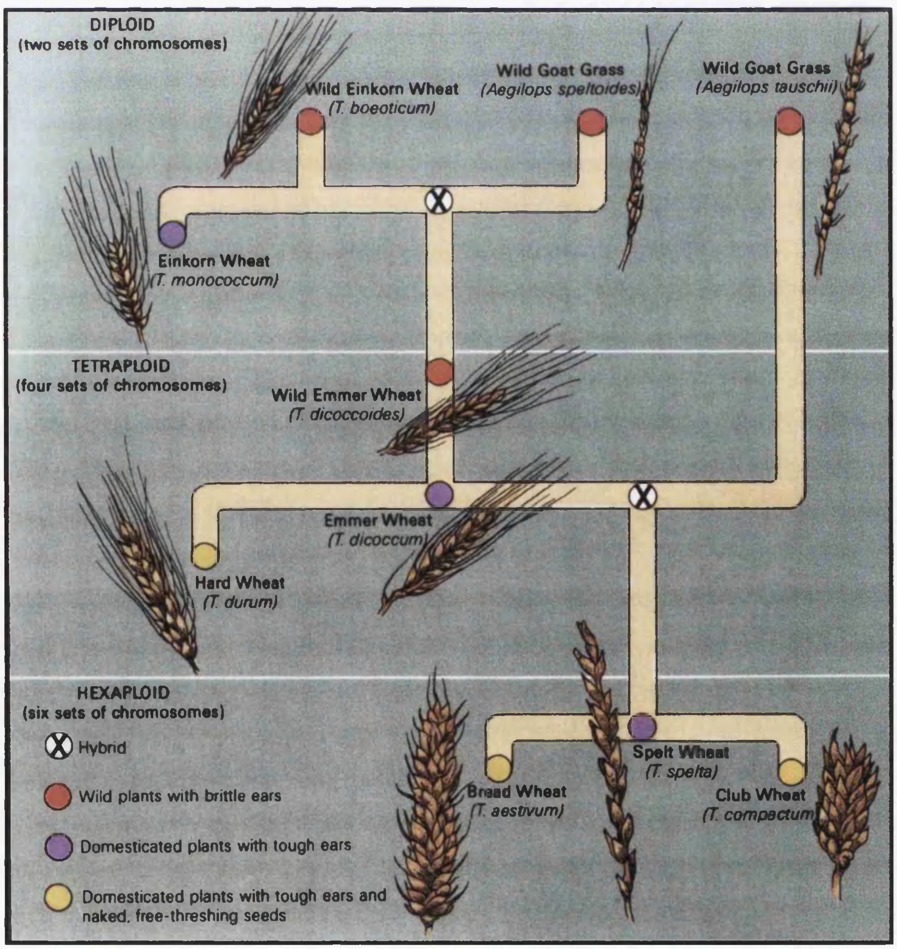



**Figure 3.15: A possible evolutionary route from diploid to haxaploid wheat**
After Roaf 1999: 29.

Grain in general, or barley, was depicted by (a) (*F.*, 32) or (b) (*F.*, 428), and later by (c) (*F.*, 270) or (d)[1] (*F.*, 130). An ear of corn (wheat) was depicted by (e) (*F.*, 70), and a seed, or posterity, by (f) and (g).

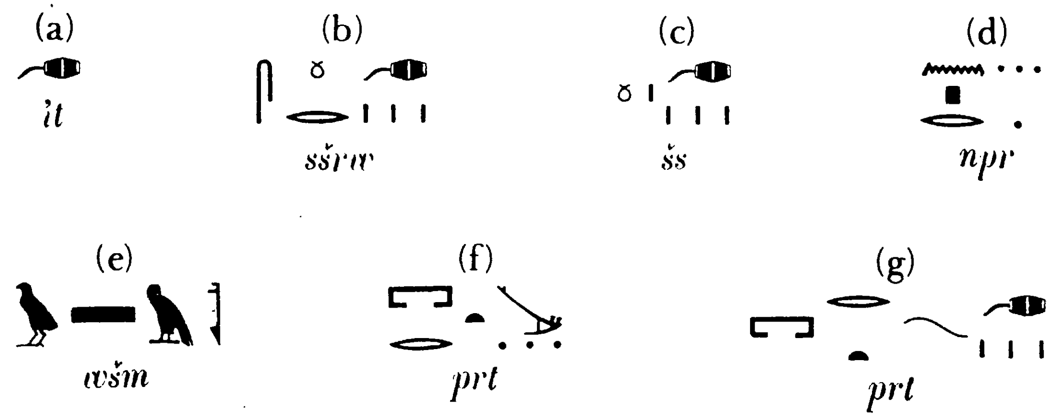



**Figure 3.16: Egyptian hieroglyphs for grain a-g and wheat j-l.**
After Darby et al 1977: 457, 486.

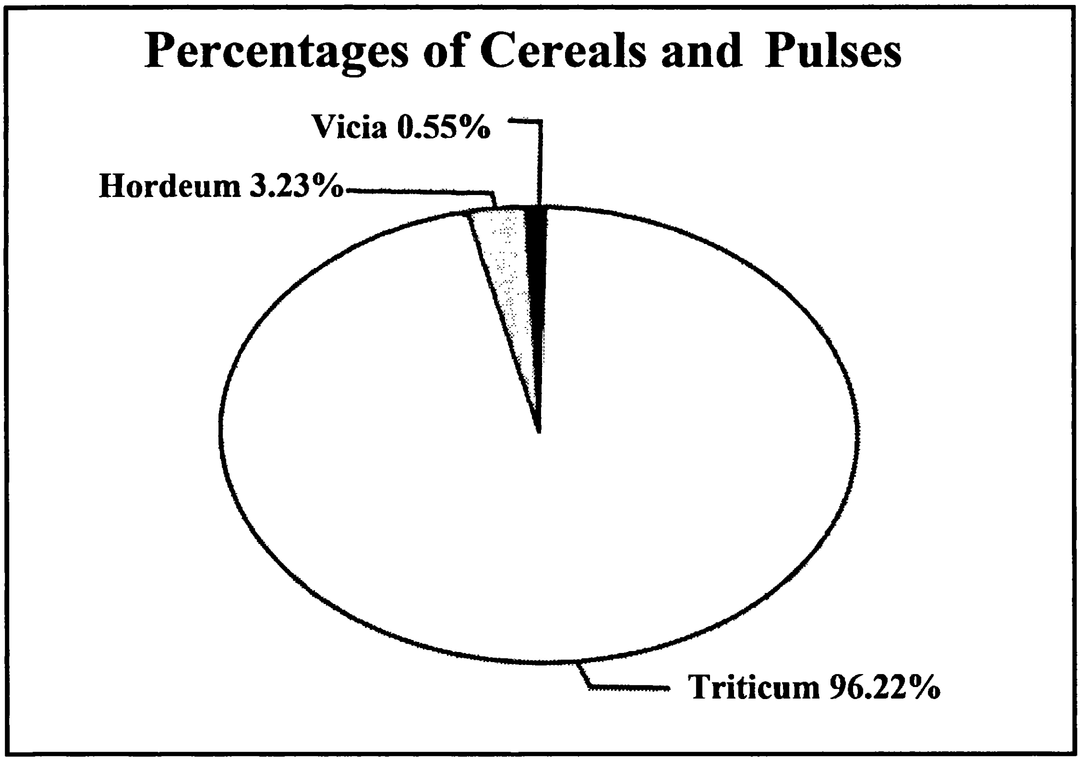



**Figure 3.17: Percentages of cereals and pulses excavated from Tel Yin'am in Canaan showing the dominance of wheat (Triticum) over barley (Hordeum) and vetch.**
After Gorham and Dering 2003: 253, graph 14.1.

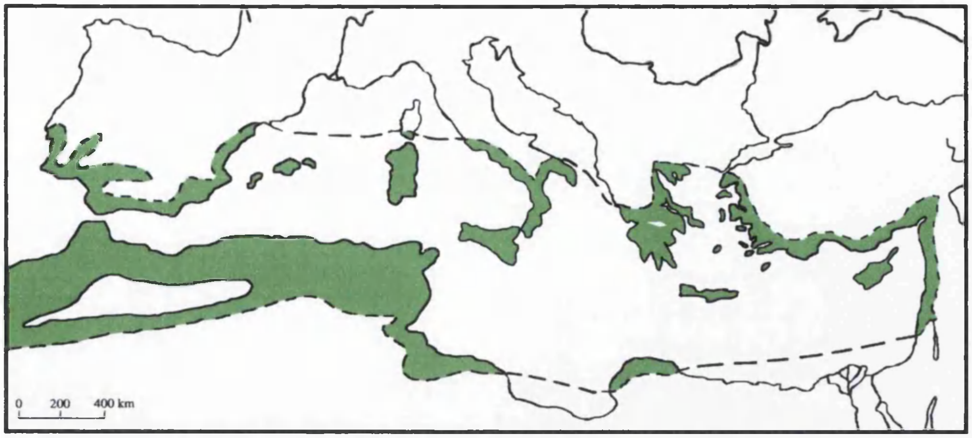



**Figure 3.18: Domestication of the Olive tree around the Mediterranean**
Zohary 1969: 146, map 1.

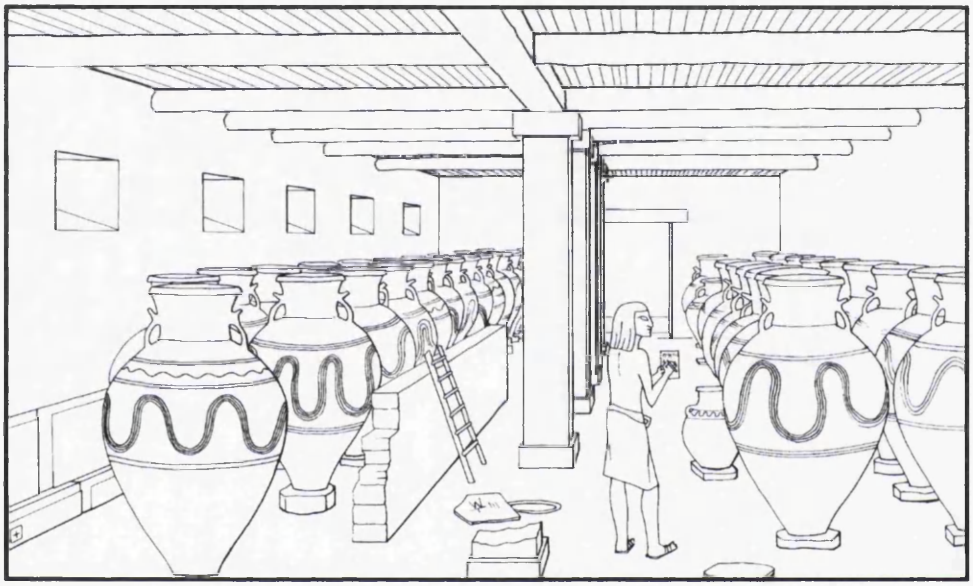


**Figure 3.19: Reconstruction of the Pithos Hall in building X with dimensions and proportions taken from excavated evidence of the site and the pithoi.**
After Keswani 1991: 142, figure 5.

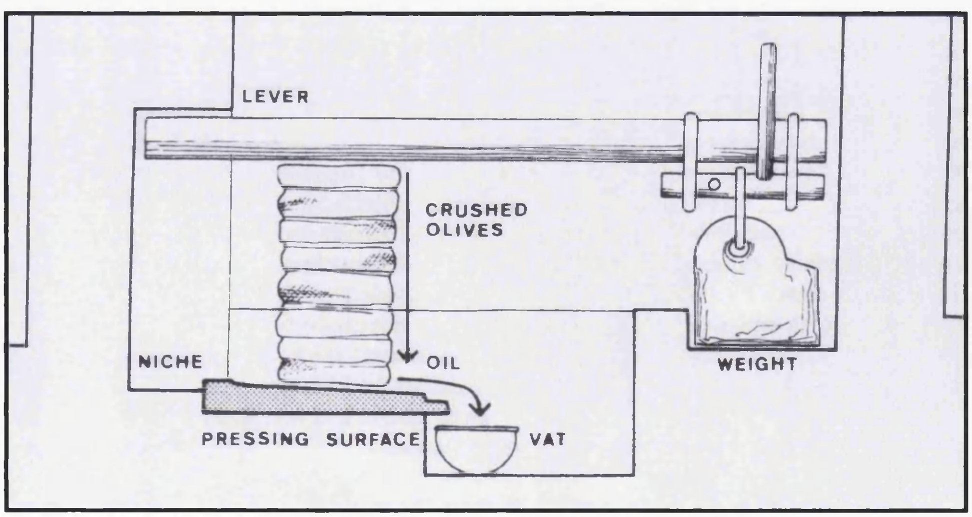



**Figure 3.20: Proposed lever press from Ras Shamra for vegetable oil production**
After Callot 1987: 208, figure 10.

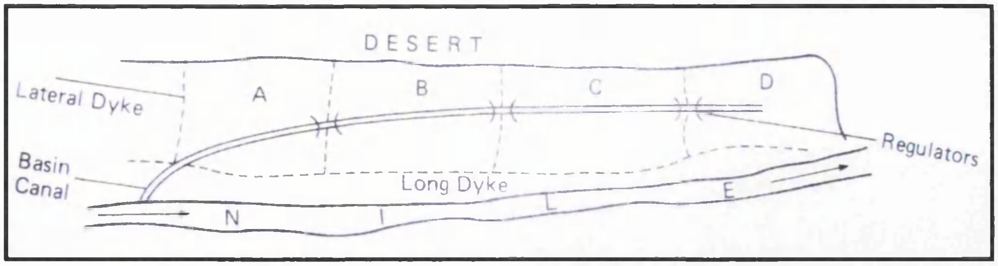



**Figure 3.21: Schematized drawing illustrating the operation of basin irrigation.**
After Lloyd 1983: 327, Figure 4.8.

**Figure 3.22: Man milking a cow who sheds a tear as she loses the milk intended for the calf tied to her leg. Sunk relief on the sarcophagus of Queen Kawit. From the temple of Mentuhotep II in Deir el-Bahri, West Thebes. 11th Dynasty.**
After Brewer et al 1994: 85.

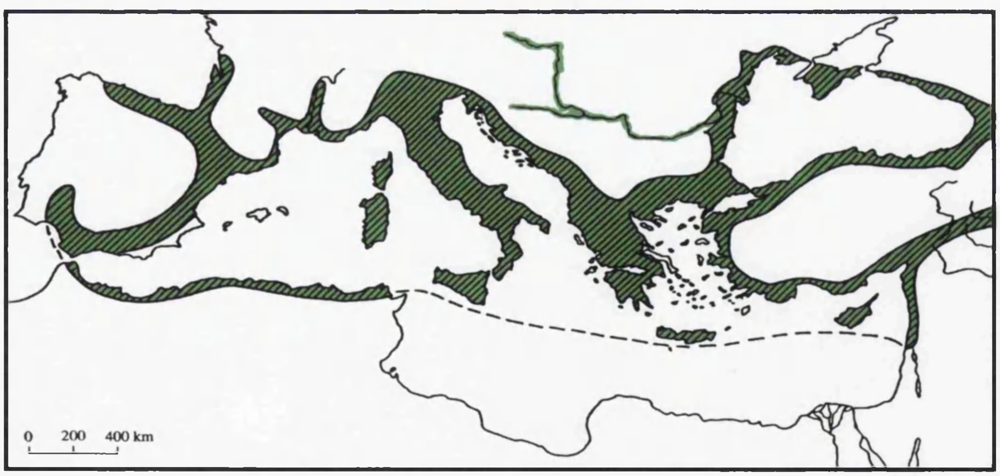



**Figure 3.23: Distribution of the wild grape vine, Vitis vinifer subsp. Sylvestris.**
Zohary and Hopf 2000: 154, map 15.

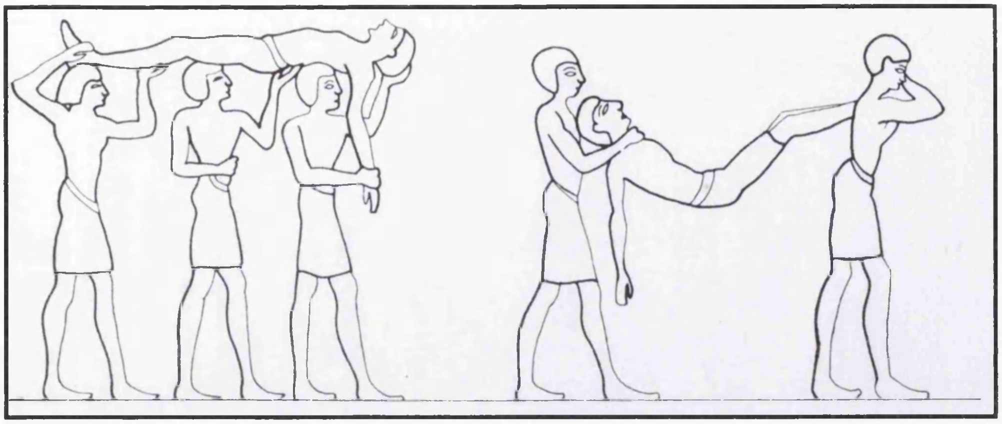


**Figure 3.24: Inebriated guests removed from a banquet. Tomb of Senna at Thebes (TT169)**
After Murray et al 2000C: 578, figure 23.3. Drawing originally published in : 168, figure 148.
Original drawing published in Wilkinson 1878: 168, figure 148

**Figure 3.25: Tomb of Nakht showing simultaneous ard ploughing and hoeing.**
After Shedid and Seidal 1996: Plate 41


**Figure 3.26: Designs of Egyptian hoes found in the archaeological record and bottom a wooden hoe from Lahun used to cultivate soil and weeding by hand.**
After Digital Egypt for Universities, Petrie Museum, University College London. 2002. Accessed 29th April 2007. Available from http://www.digitalegypt.ucl.ac.uk//lahun/ucarchivelahun/uc16694.jpg.

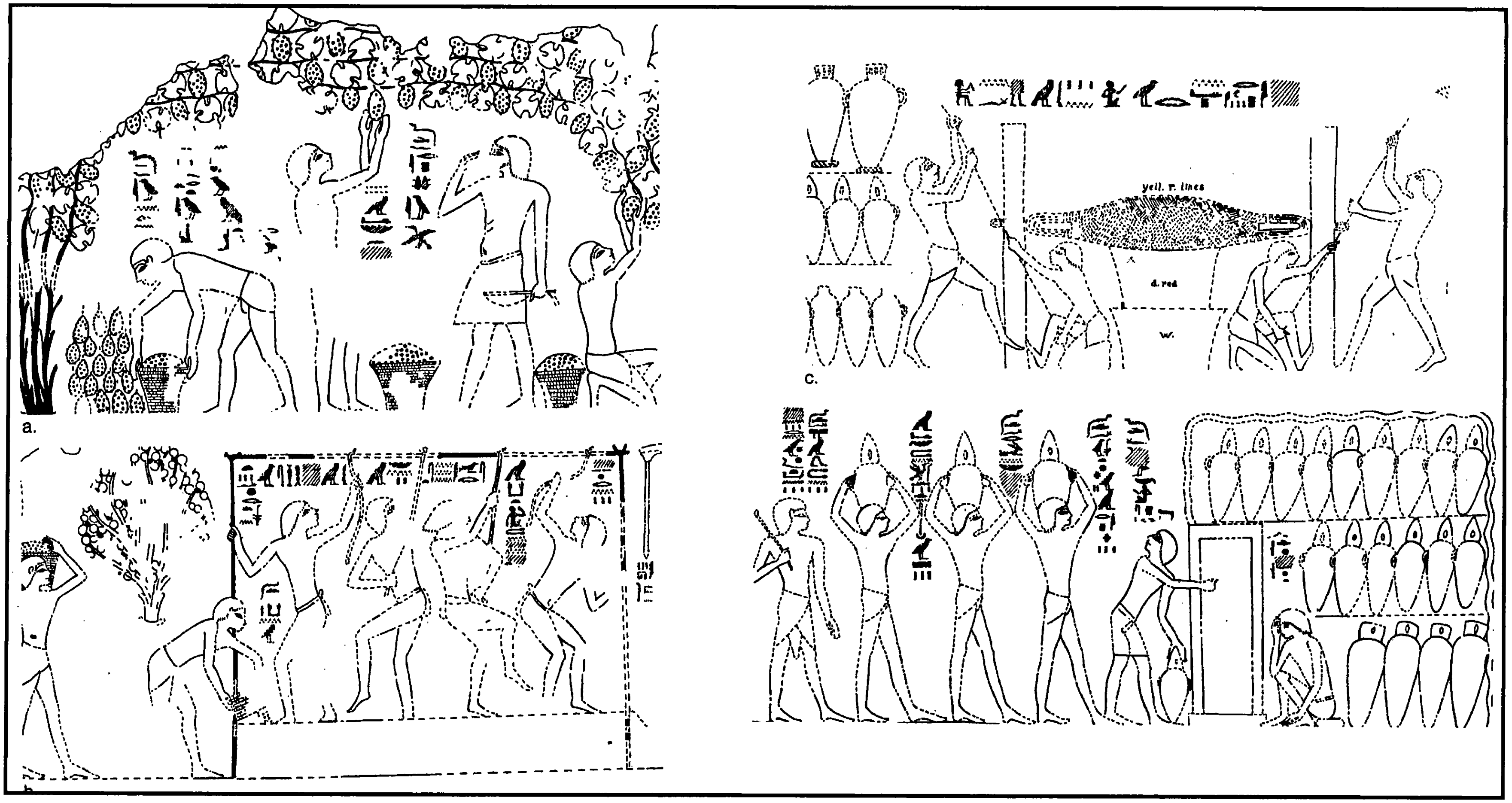



**Figure 3.27: The Egyptian winemaking process as demonstrated in the 18th Dynasty Tomb of Intef.**
After McGovern 2003: 142-143, Figure 6.6.

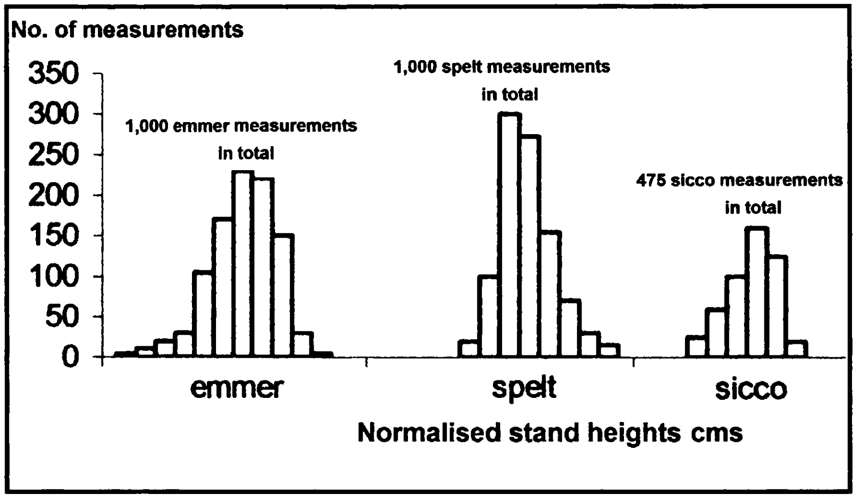



**Figure 3.28: Normalised stand heights of emmer and spelt compared with modern sicco wheat.**
After Reynolds 1992: 11, figure 2.

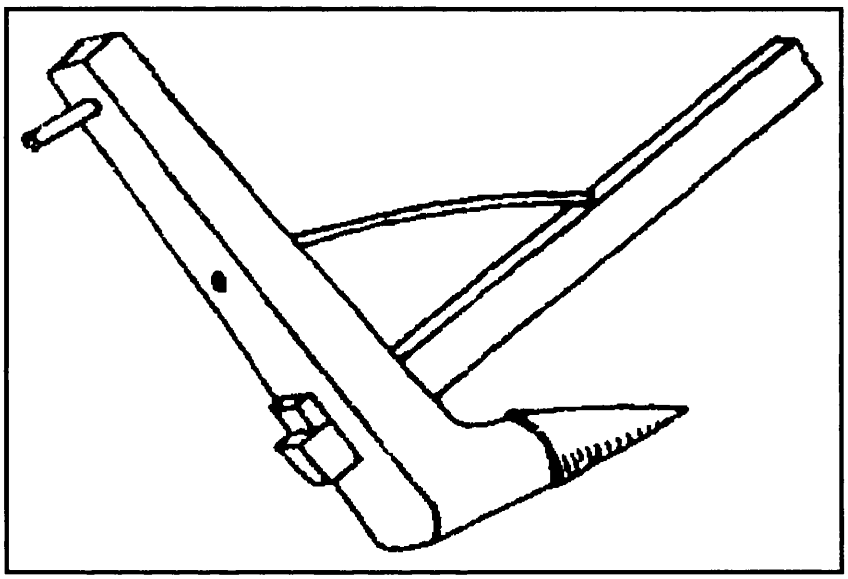


**Figure 3.29: Generic design of the symmetrical ard**
Skakun: 1991: 201, figure 21.4

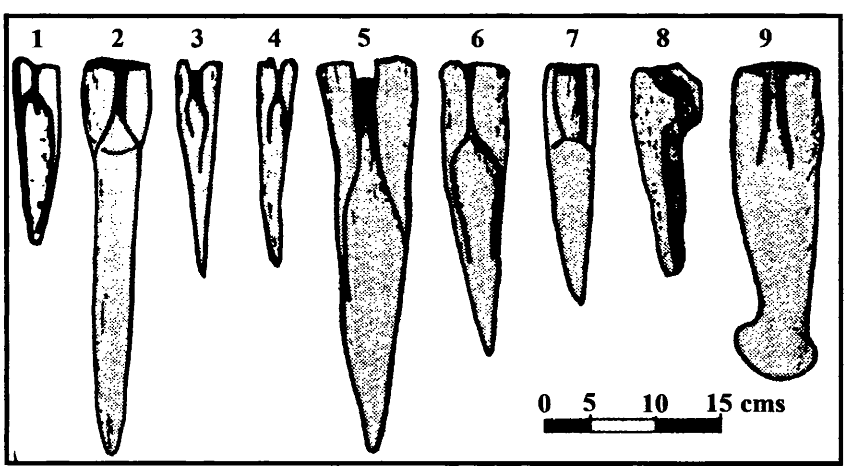



**Figure 3.30: Bronze and iron plough points found across Southern Levant**
After Borowski 1987: 51, figure 4.

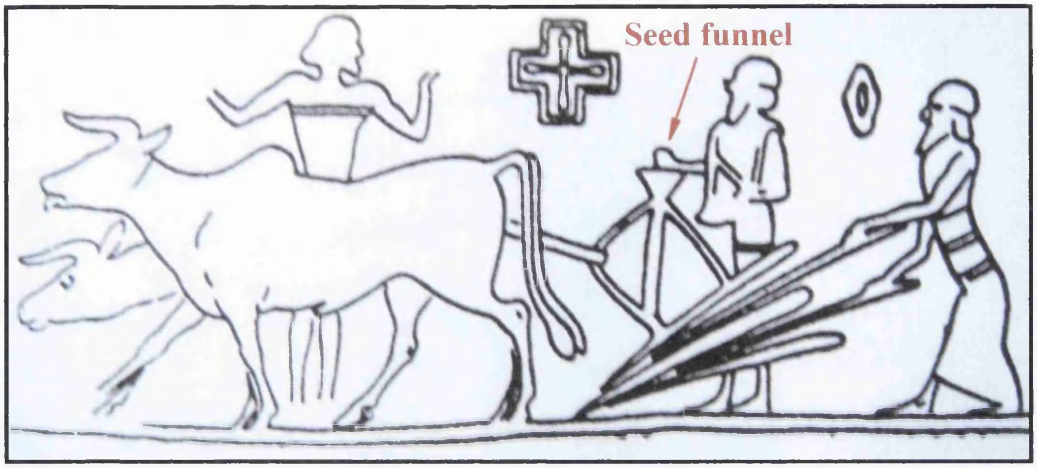



**Figure 3.31: A Babylonian seed drill; from a Kassite seal impression. University Museum, University of Pennsylvania, Philadelphia.**
Adapted from Eyre 1995: 182.

**Figure 3.32: Third Millennium models of ploughing scenes from Vounous in Cyprus.**
After Karageorghis 1981: 44, catalogue no. 30.

**Figure 3.33: Tomb of Paheri, Lower register showing oxen drawn and human drawn ards, and hoes, preparing soil for sowing and broadcast sowing. Upper register showing reaping and binding of sheaths prior to transport to the threshing point.**
Adapted from http://www.osirisnet.net/tombes/el_kab/e_el_kab.htm, accessed 29th August 2008, drawing of photograph from Taylor: 1895, Plate IV.

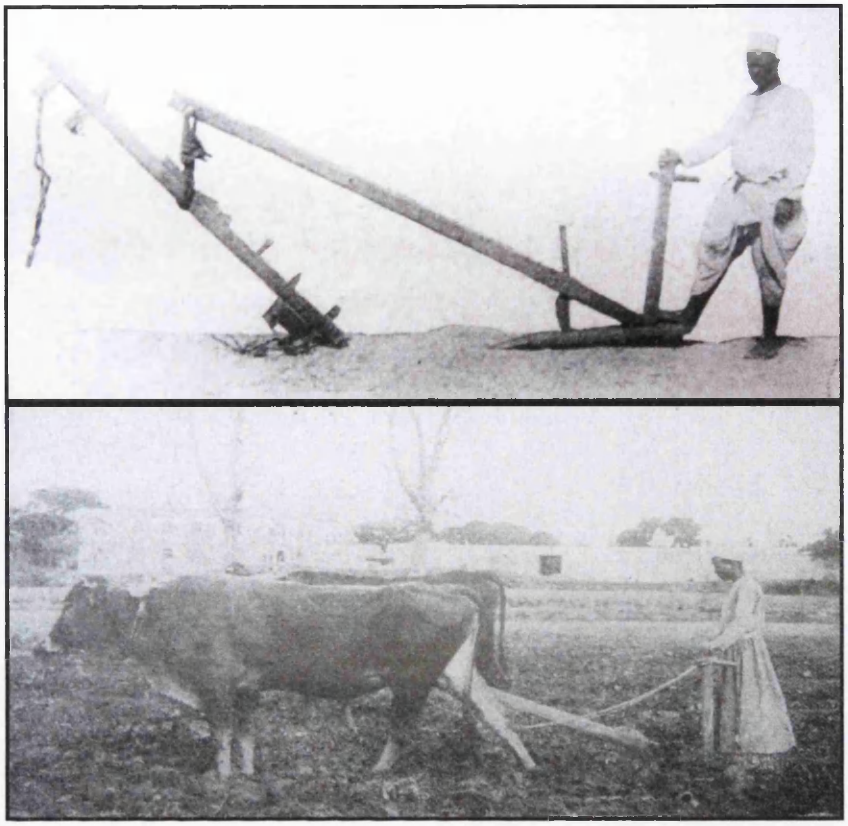


**Figure 3.34: Egyptian Beladi Plough**
After Foaden and Fletcher 1908: 111, Plates 9a and 9b.

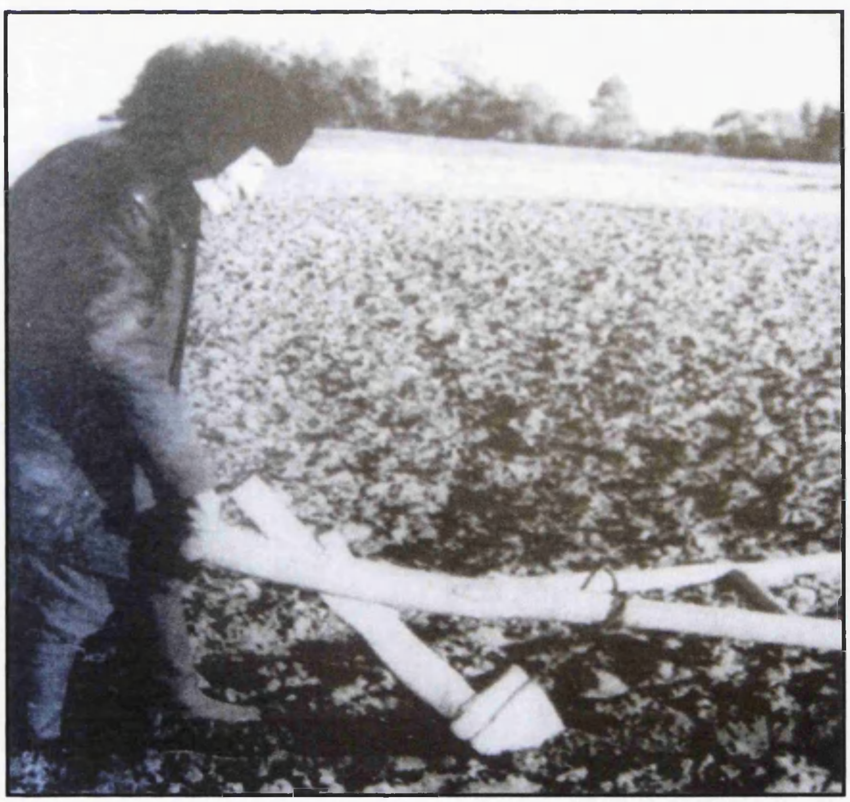


**Figure 3.35: Symmetrical ard in use in the early Twentieth Century A.D. in Bulgaria.**
After Russell 1988, 118 figure 15, and bottom.

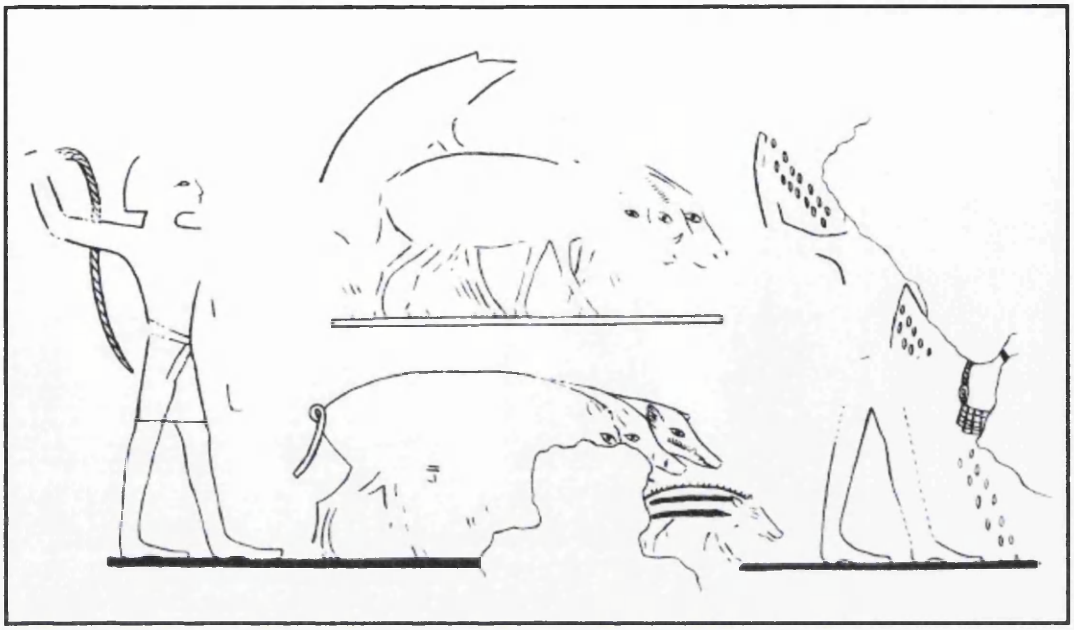


**Figure 3.36: Pigs trampling in seed after broadcast sowing. Tomb of Nebamon (TT 24 at Thebes).**
After Newberry 1928: 218, Figure 2.

**Figure 3.37: Criss-cross ard marks at Skaill Orkney.**
After Rees 1981: 36.

**Figure 3.38: Broadcast sowing in the Tomb of Paheri at El Kab (Tomb EK3).**
After Tylor: 1895, Plate IV.

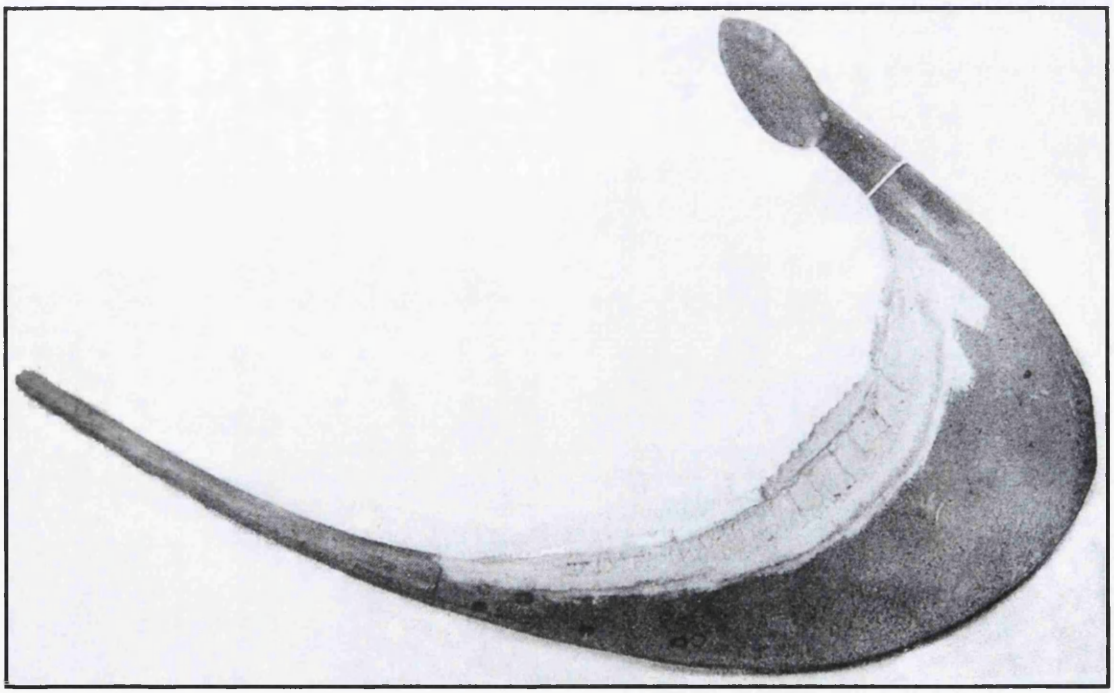


**Figure 3.39: Sickle with inset serrated chipped stones.**
After Murray 2000: 521, Figure 21.8.

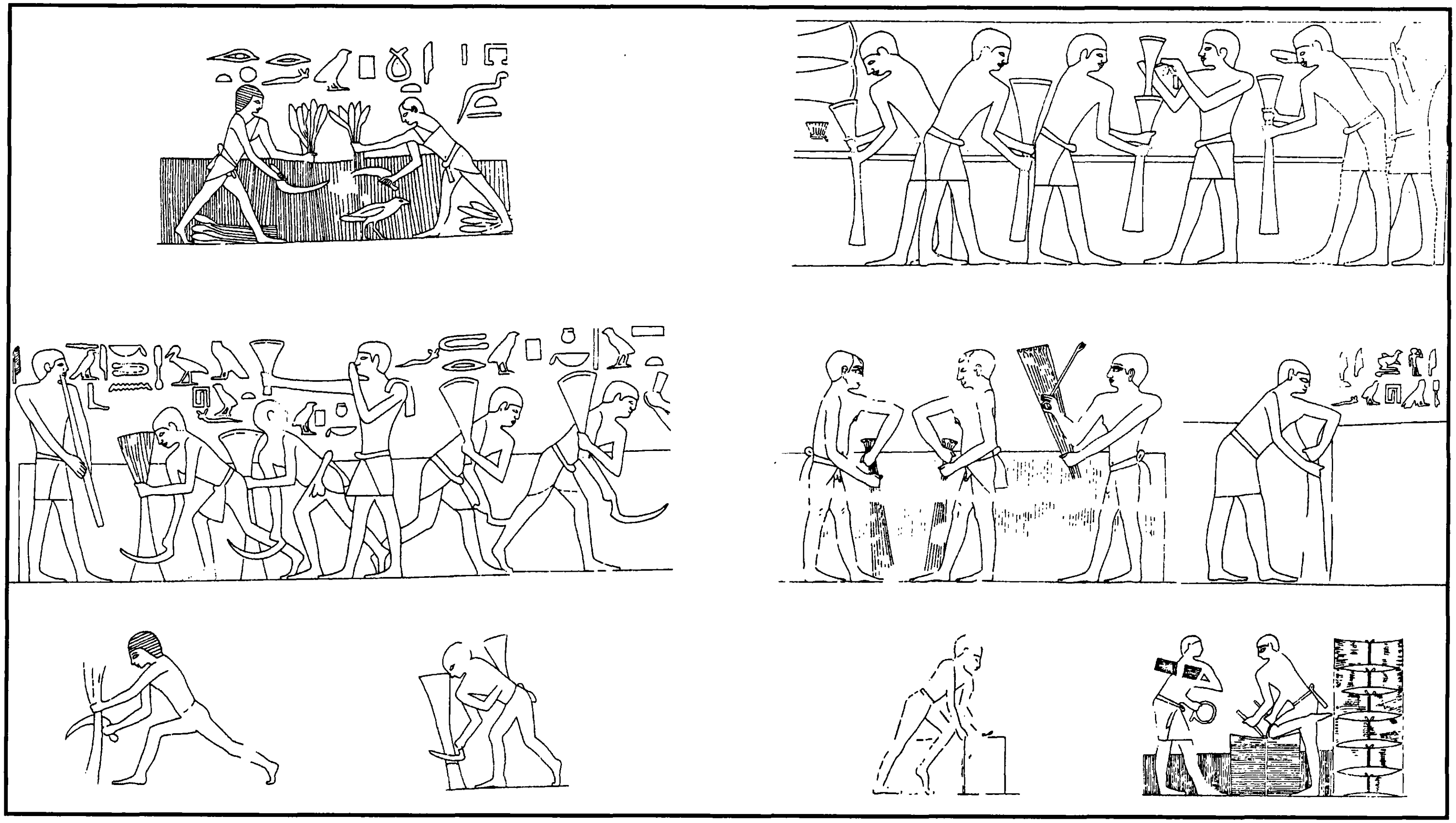


**Figure 3.40: The Egyptian harvest. Reaping and binding of sheaves from a painting in the chapel of *Jbj* at Deir el-Gabrawi.**
After Harpur 1987: 506-507.

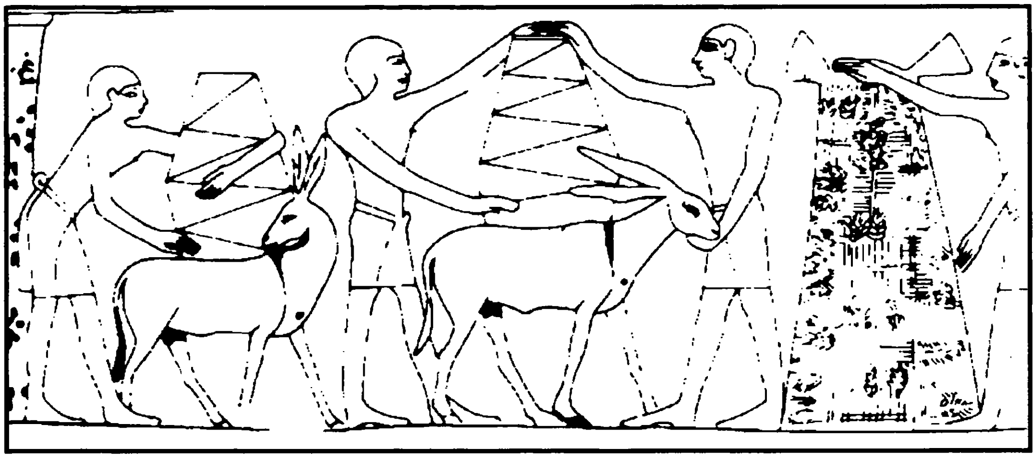


**Figure 3.41: Transporting bound sheaves to the threshing house from the Tomb of Pepyankhheryib at Meir. Dynasty 6 Old Kingdom.**
After Kanawati 2001: 88, Figure 91.

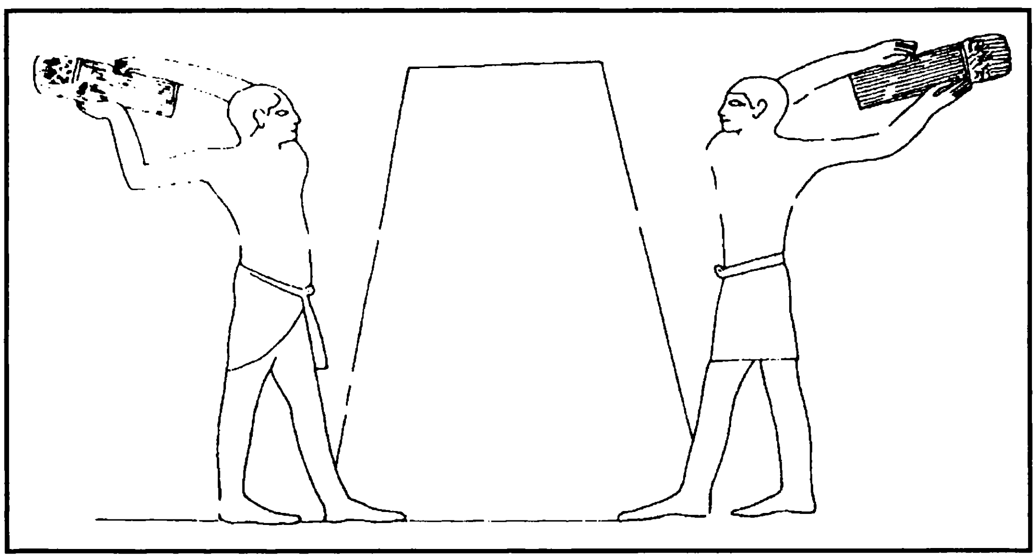


**Figure 3.42: Loading sheaves awaiting threshing from the Tomb of Mereruka at Saqqara. Dynasty 6 Old Kingdom.**
After Harpur 1987: 510, figure 153.

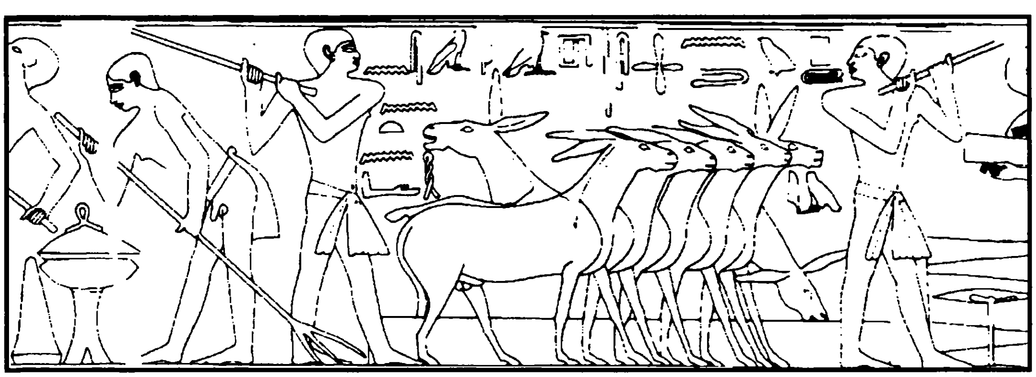


**Figure 3.43: Donkeys threshing grain by trampling from the tomb of Ankmahor, Saqqara, 6th Dynasty.**
After Kenawati 2001: 88, Figure 92.

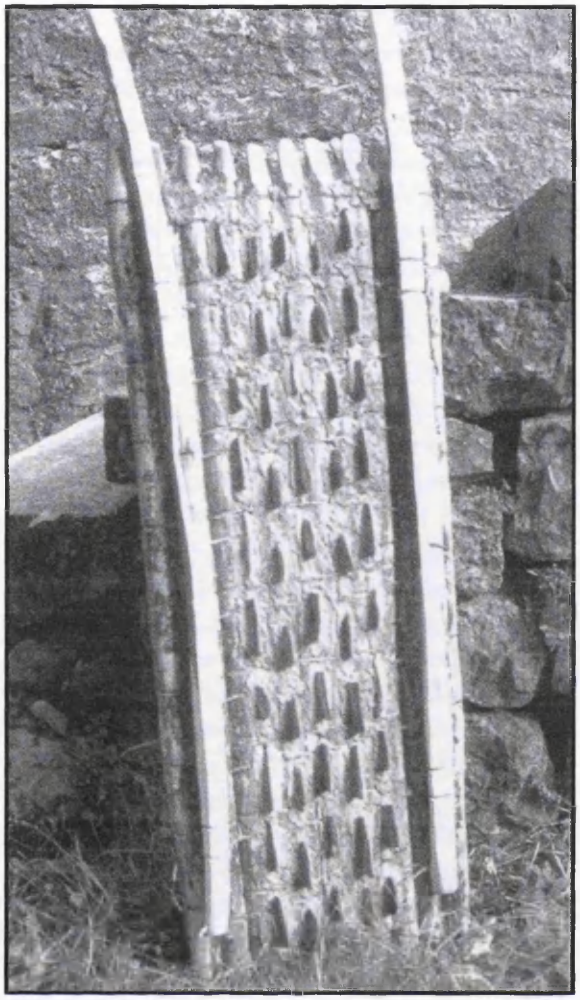


**Figure 3.44: Traditional threshing sledge with flint inserts.**
After Anderson 1999: Figure 12.29.

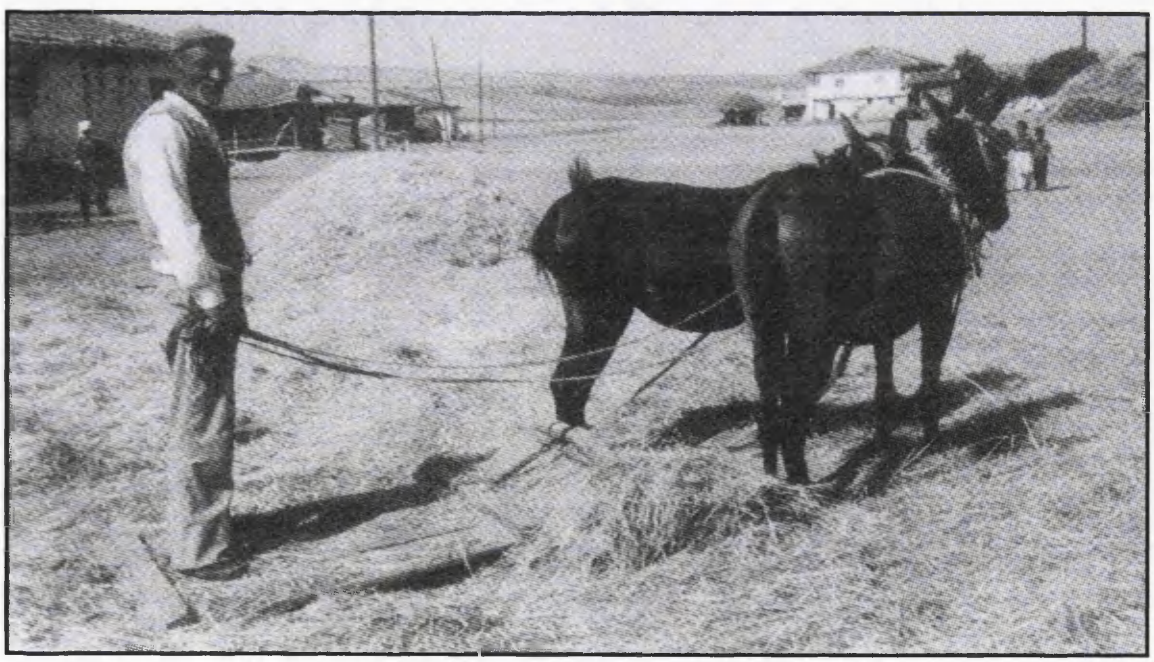


**Figure 3.45: Threshing sledge in use pulled by two horses in rural Turkey.**
After Ataman 1999: 212, Figure 22.3.

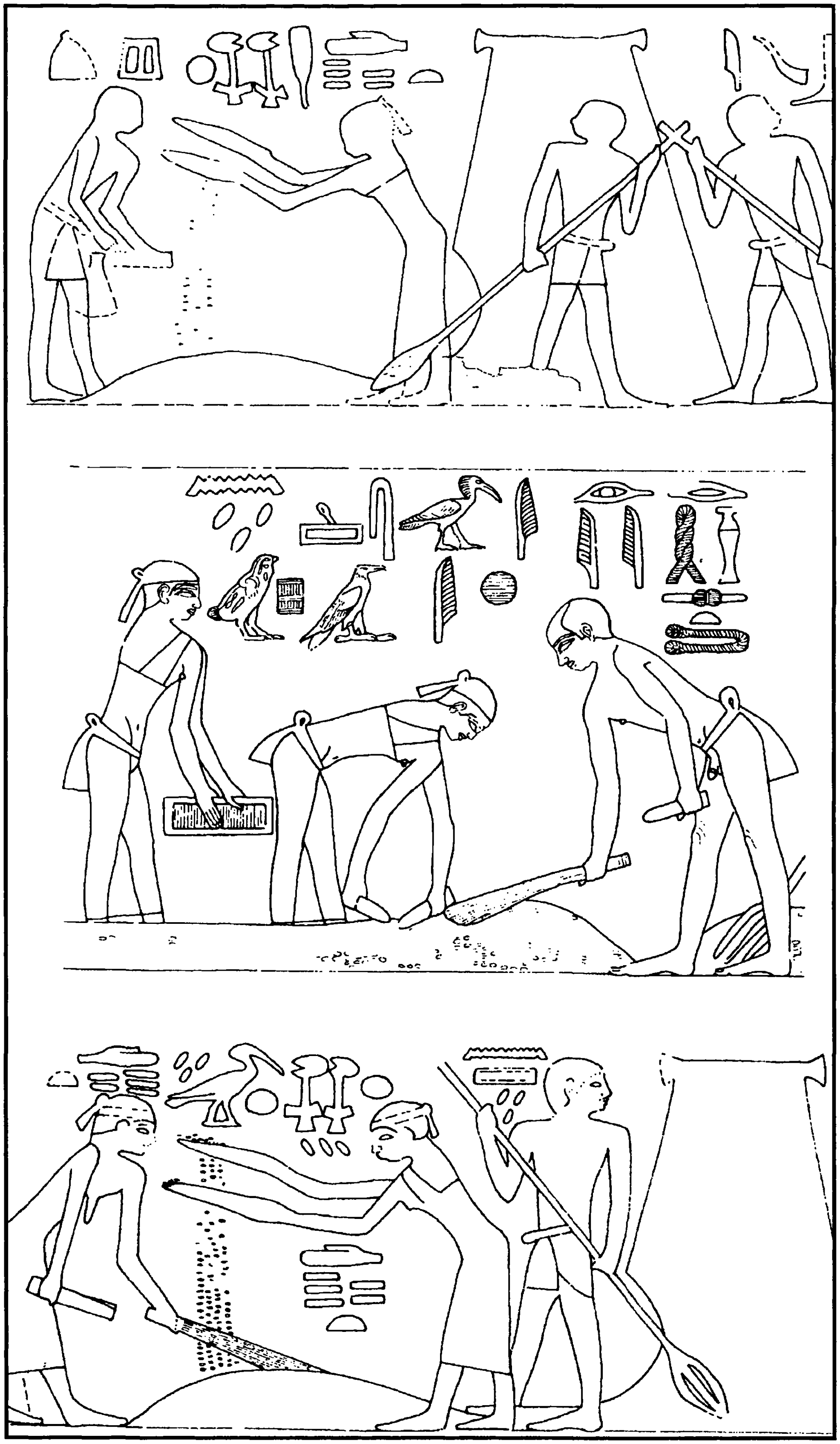


**Figure 3.46: Winnowing scenes from the Old Kingdom tombs of *K3-hj.f*, *Tjj*, and *Niˁnśhśhnum*.**
After Harpur 1987: 511, Figures 154-156.

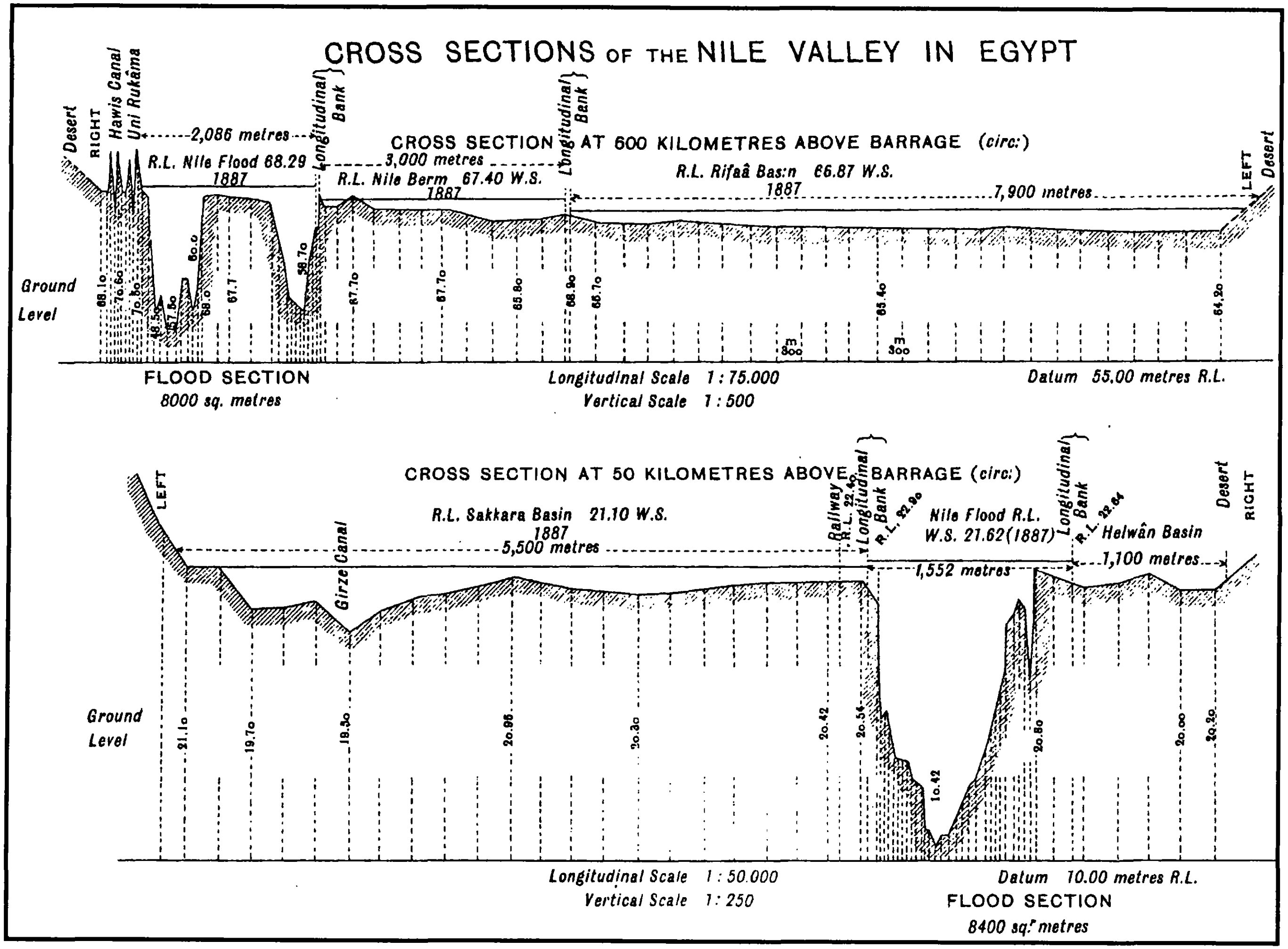



**Figure 3.47: Cross-sections of the Nile Valley showing ancient levees and convex natural basins.**
After Wilcox 1904: 51

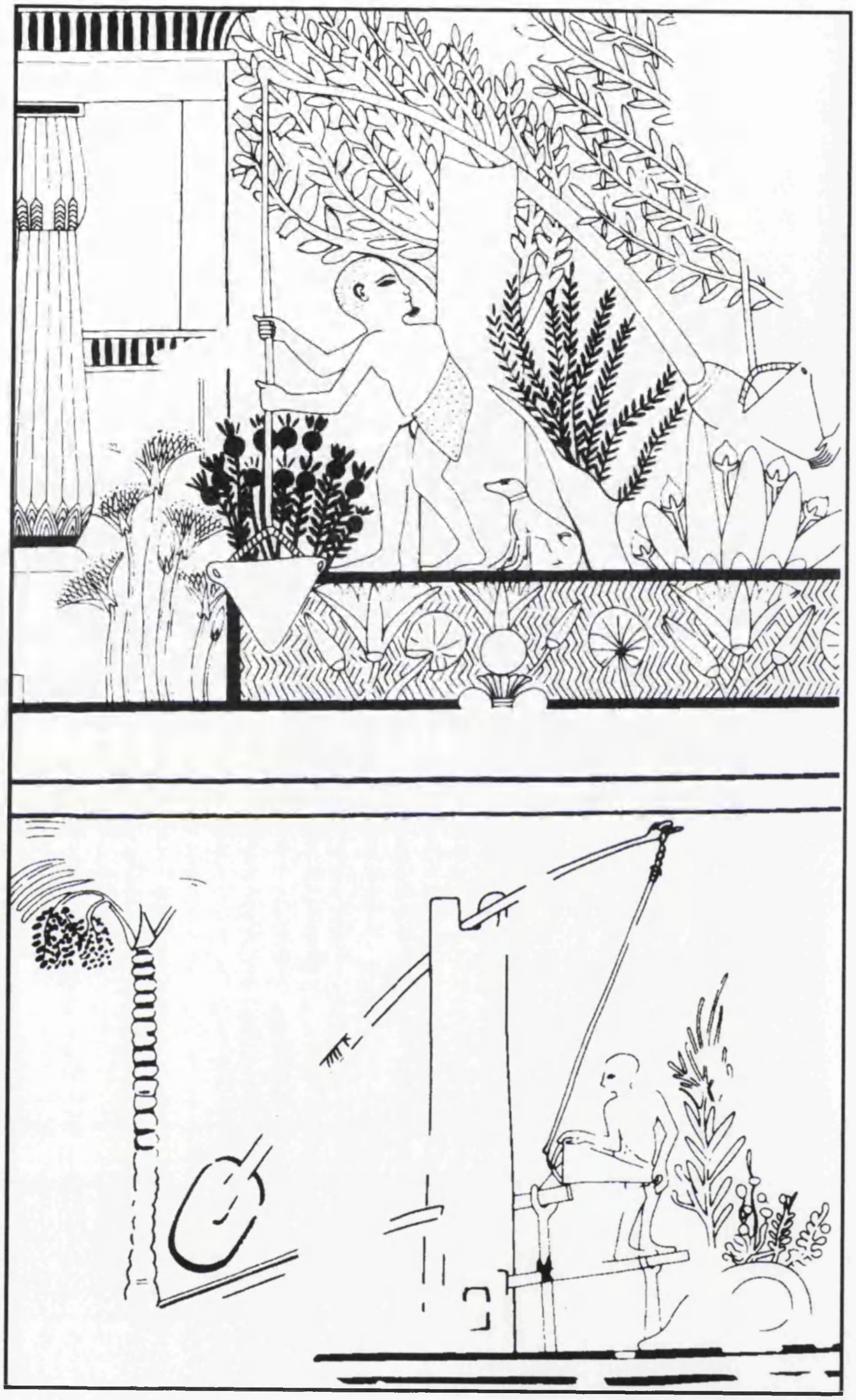


**Figure 3.48: New Kingdom shadufs ca. 1250 B.C. from the Tomb of Ipy.**
Kemp 1991: 12, Figure 12, top after N. de G. Davies, 1927, Two Ramesside Tombs at Thebes, New York, Plate XXIX , bottom after N. de G. Davies, 1933, the Tomb of Nefer-hotep at Thebes, New York, Plate XLVI.

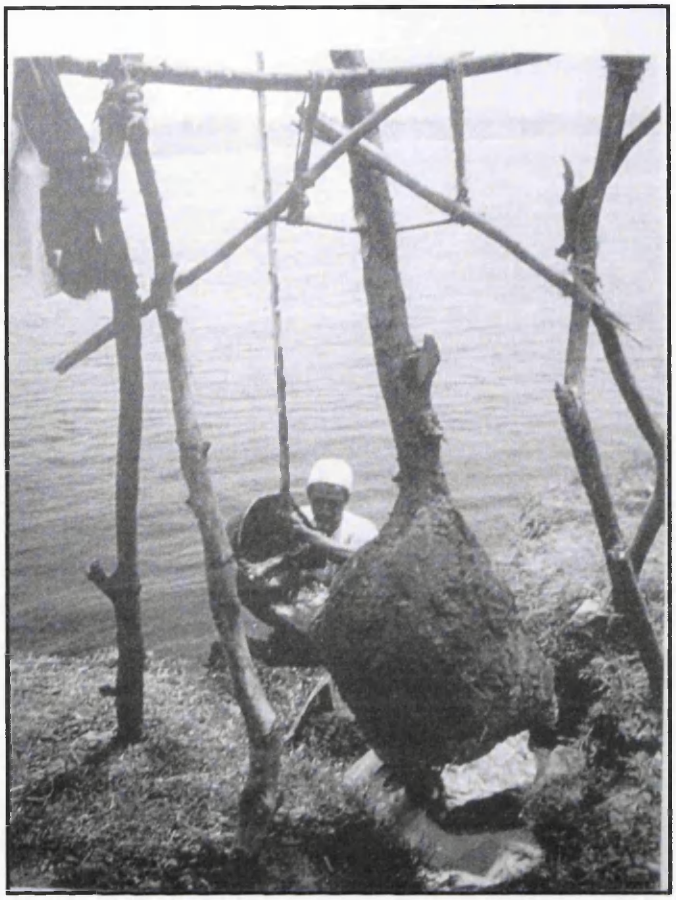


**Figure 3.49: Shaduf lifting water from the Nile into irrigation channels.**
After Borowski 1999: 184.

**Figure 3.50: Example of three shadufs operating in tandem.**
After Breasted 1905: 167-168 [text], Vol. 1; Stereograph 35, copyright 1898 Underwood and Underwood, Vol. 2 [maps and plates].

# Chapter 4 Figures: Cloth

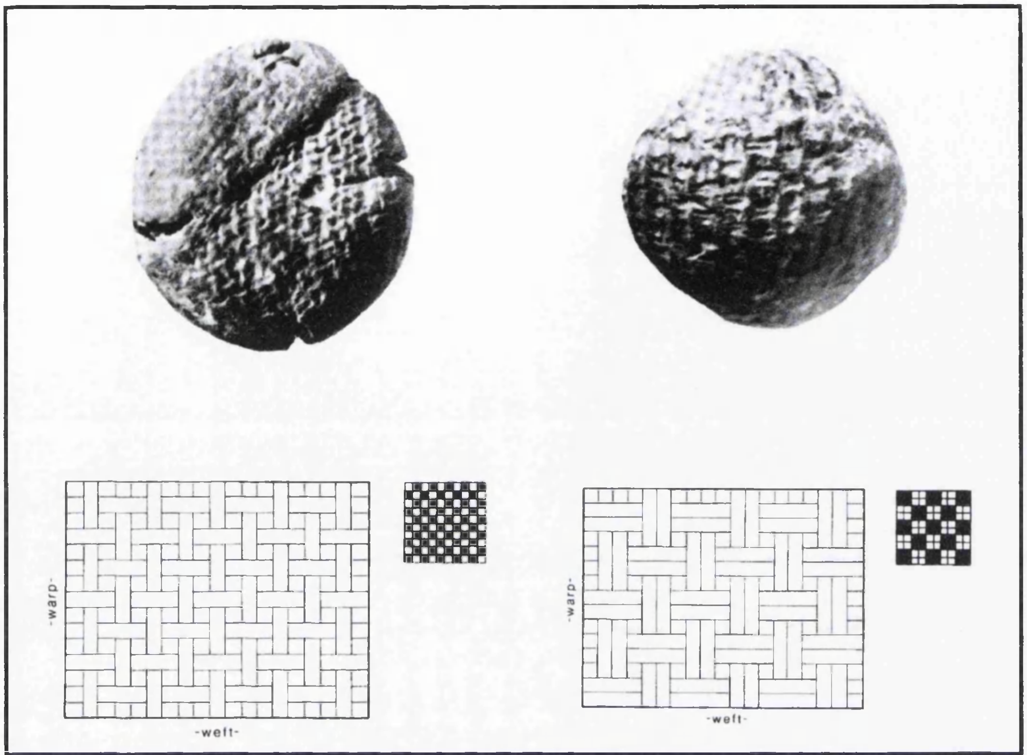



**Figure 4.1: Impressions of plain (upper left) and basket weave (upper right) found at Jarmo, north-eastern Iraq. Dated to early seventh millennium B.C.**
Textile impressions after Adovasio 1975: 224-225, Figure 1 and 3. Weave patterns after Kemp and Vogelsang-Eastwood 2002: 92-93, Figures 4.4-4.5.

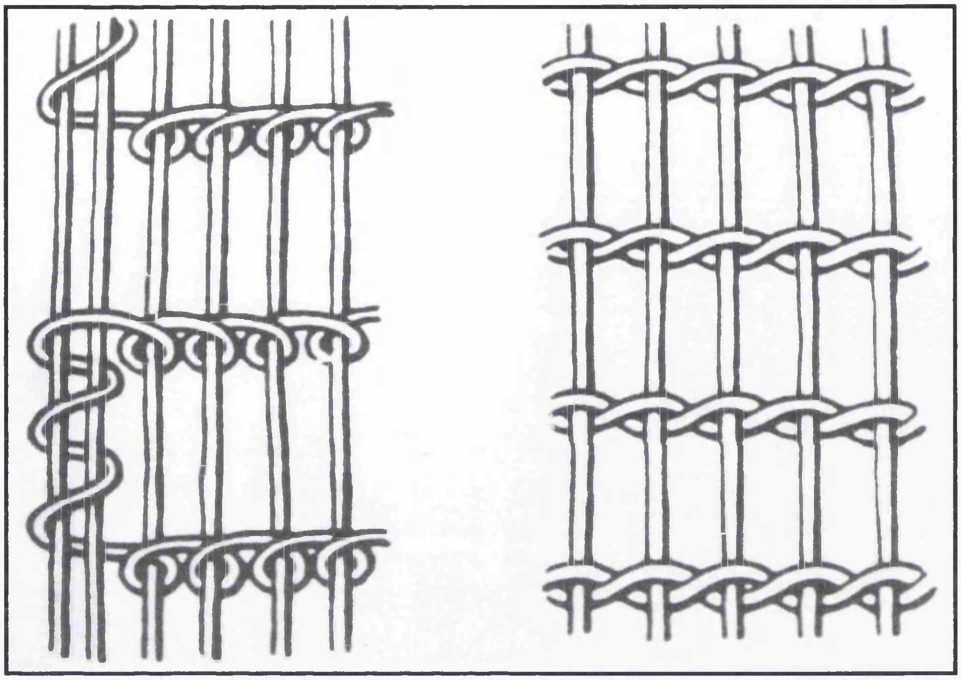


**Figure 4.2: Illustrations of weft-wrapping (left) and weft-twinning with paired wefts (right). Evidence taken from samples found in Çatal Hüyük ca. 6000 B.C.**
After Burnham 1965: 171, Figures 1-2.

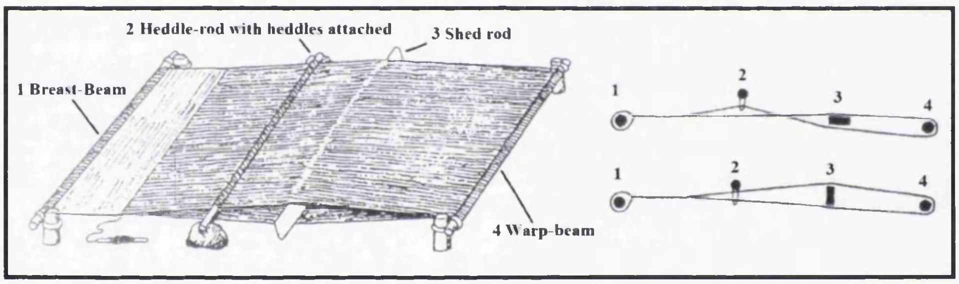



**Figure 4.3: Horizontal beam with side elevations showing operation.**
Adapted and corrected from Wilson 1933: 6, Figures 1 and 2.

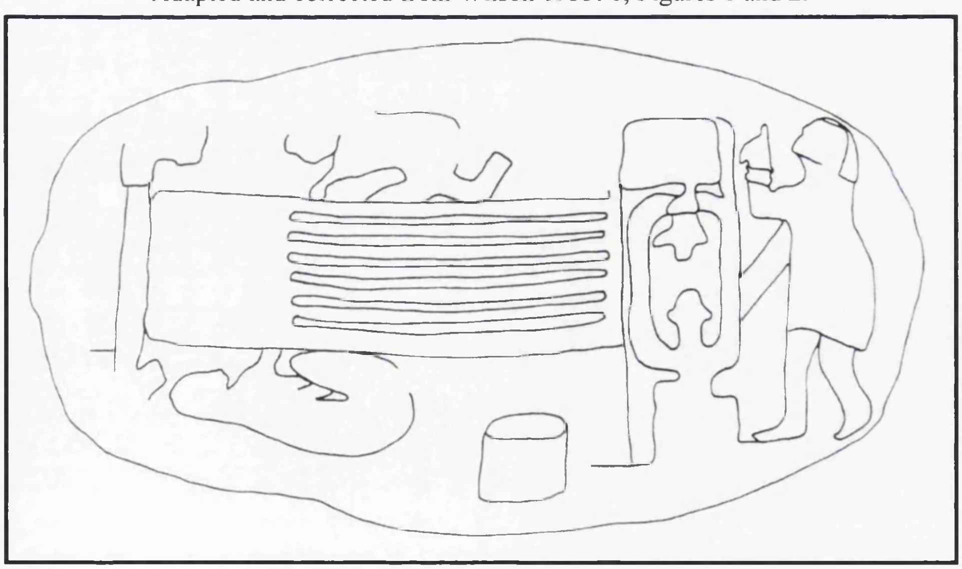


**Figure 4.4: Seal from Susa (not before 3000 B.C.) showing the operation of a horizontal loom.**
After Wild 2003c: 46, Illustration I.12.

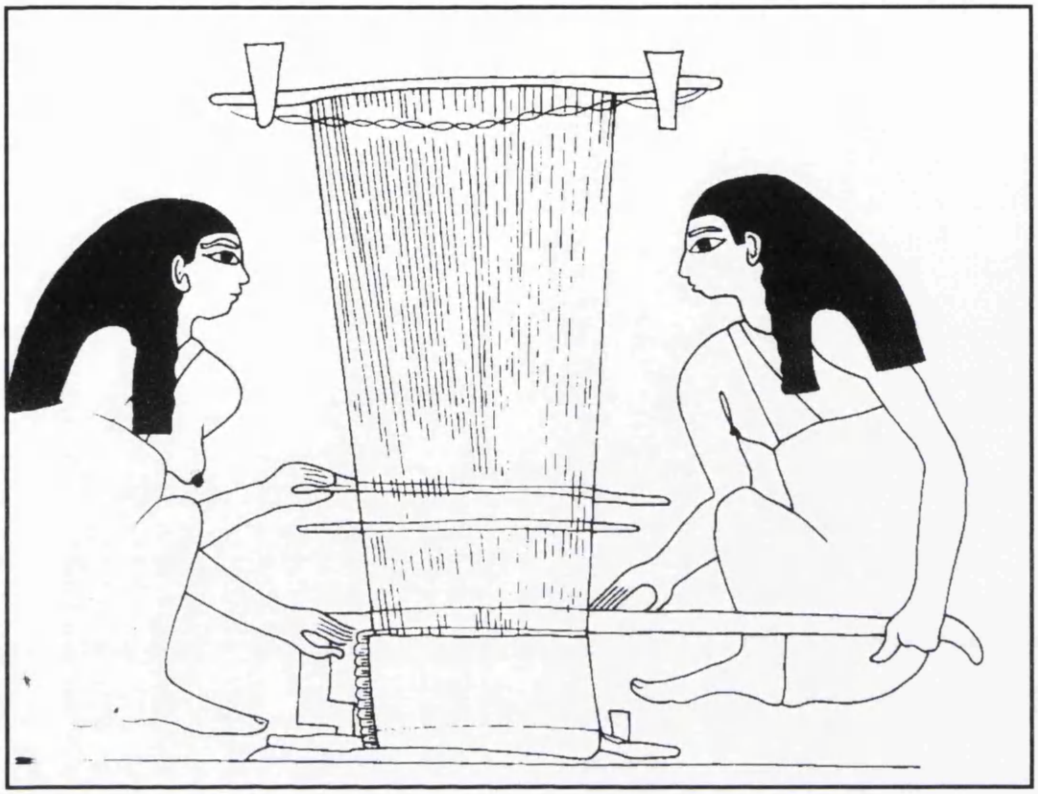


**Figure 4.5: Ground loom seen in plan elevation, from the Middle Kingdom tomb of Khnumhotep III at Beni Hasan (BH3).**
Vogelsang-Eastwood 2000: 277, Figures 11.7 after Newberry 1893: pl. XXIX, Beni Hasan I. London, Egypt Exploration Fund.

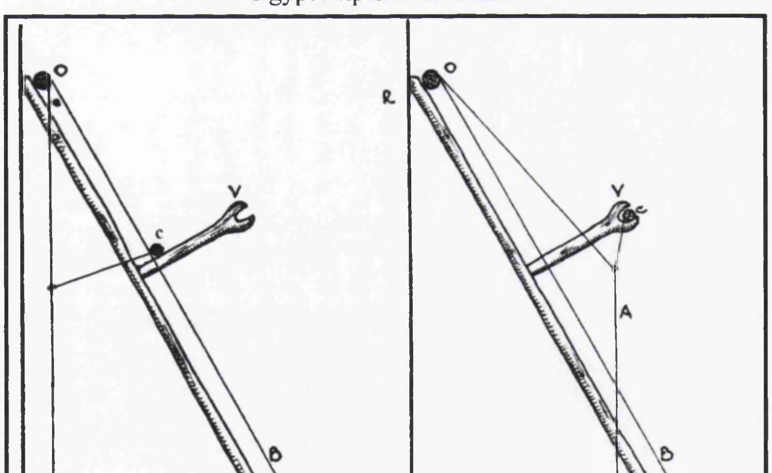


**Figure 4.6: Cross-section of vertical looms, showing that they were inclined and the warp B tensioned using weights tied at the bottom. Lifting alternate warps attached to c into the heddle Y provides the gap to pass the shuttle and weave the weft.**
After Wilson 1933: 6.

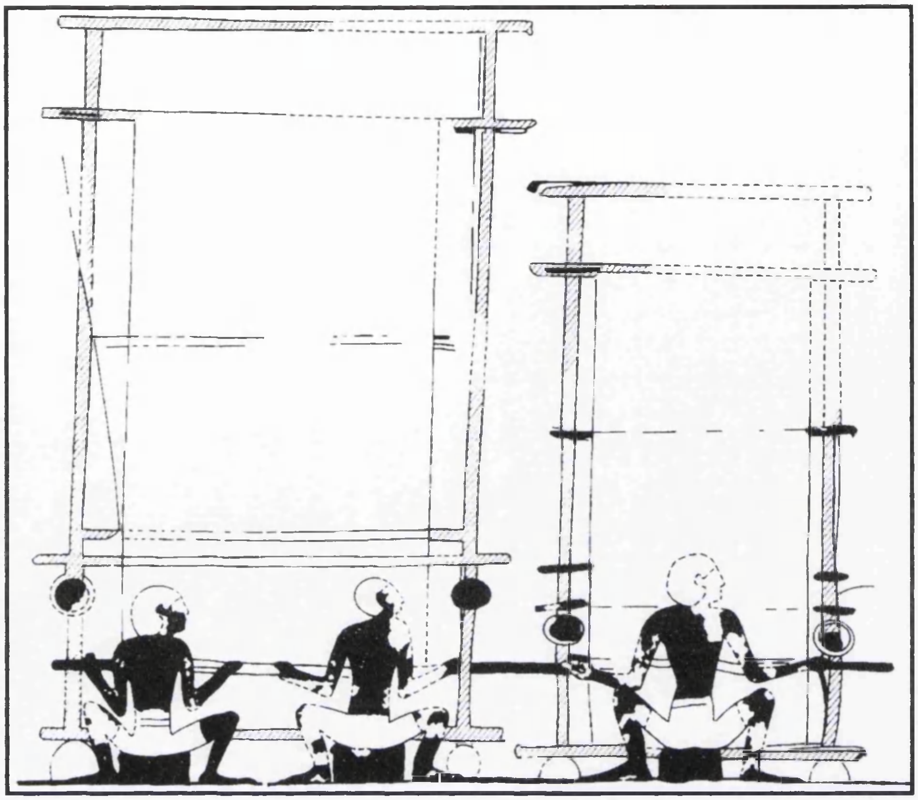


**Figure 4.7: The earliest representation of the Egyptian vertical two-beam loom, New Kingdom ca. 1478-1479 B.C. Tomb of Thutnefer at Thebes (TT104).**
Vogelsang-Eastwood 2000: 277, Figure 11.8 after Davies N. de G. 1929: "The Town House in Ancient Egypt." Metropolitan Museum Studies 1.2: 234, Figure 1. Dating by Kampp 1996: 14


**Figure 4.8: The First Dynasty 'Tarkhan' dress of plain-weave linen cloth (ca. 3000 B.C.).**
After Quirke, S. 2003. Textile Production and Clothing: Technology and Tools in Ancient Egypt. Accessed 21st May 2007. Available from http://www.digitalegypt.ucl.ac.uk//textil/tools.html. London: Digital Egypt for Universities. University College London.

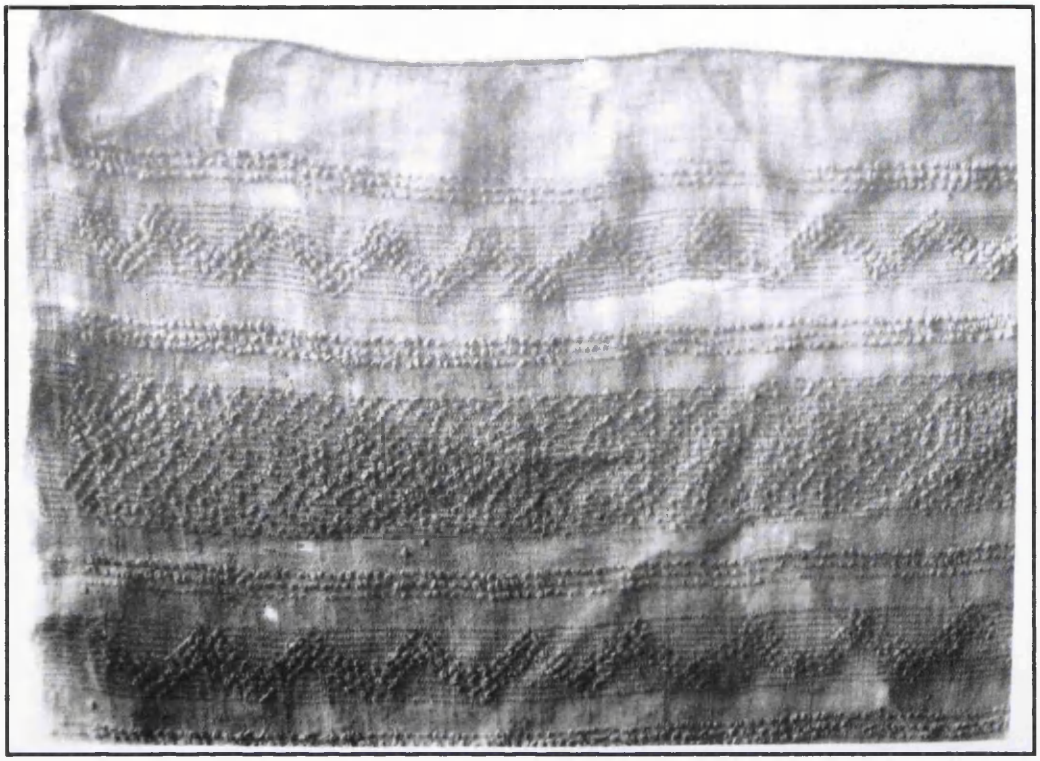


**Figure 4.9: Linen sheet with weft-looping from the Eleventh Dynasty tomb at Deir el-Bahri.**
After Winlock 1942: Plate 37.

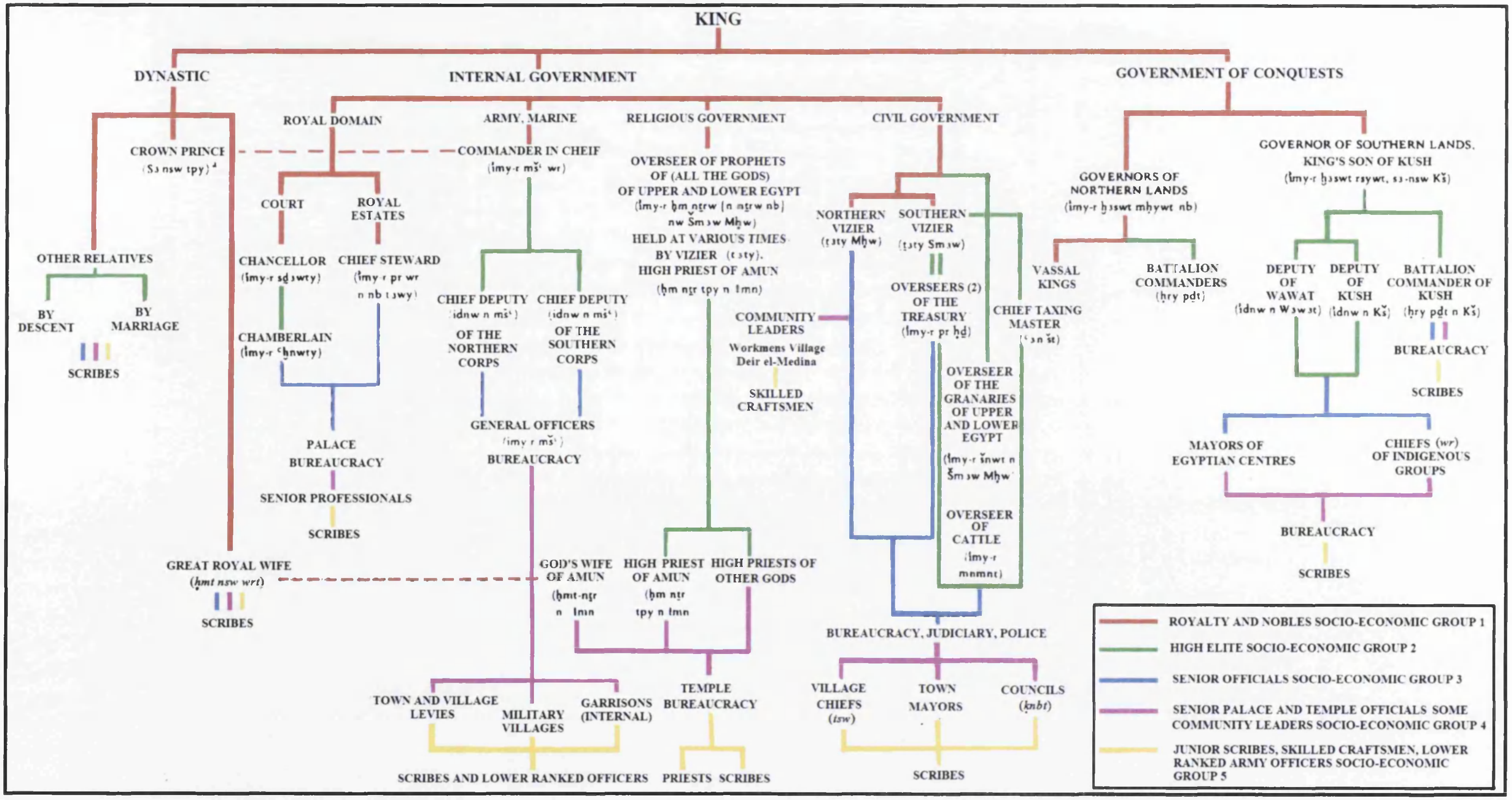



**Figure 4.10: Socio-economic structure of the New Kingdom Government in the New Kingdom.**
Adapted from O'Connor 1983: 208, Figure 3.4.

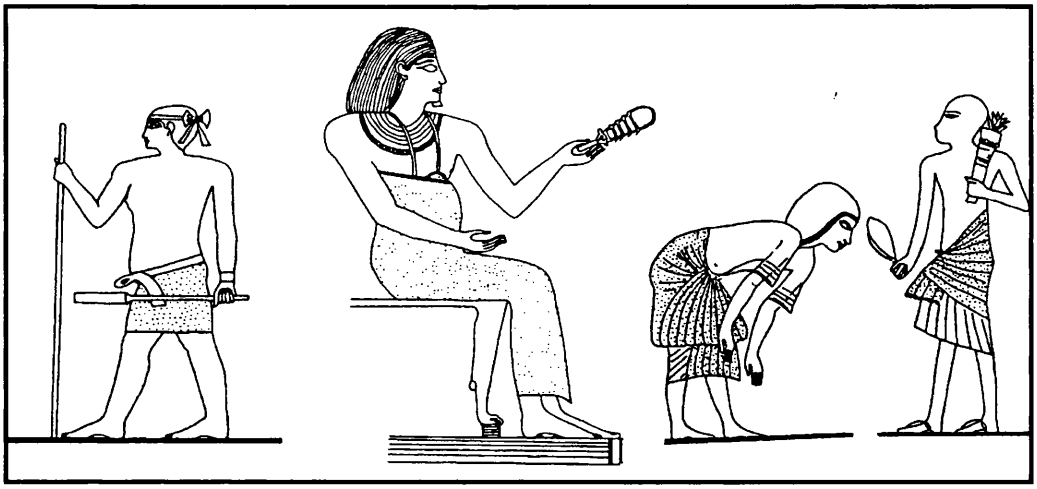
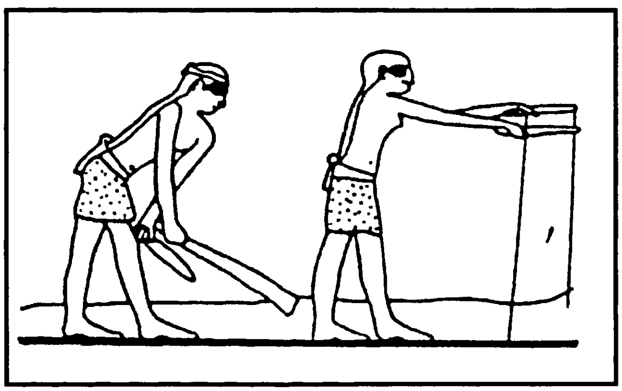


**Figure 4.11: Three kilt designs from New Kingdom Egypt. Left man wearing a short kilt, middle man a long kilt, and right man a long sash kilt.**
After Vogelsang-Eastwood, G. 1992a: 14-15.



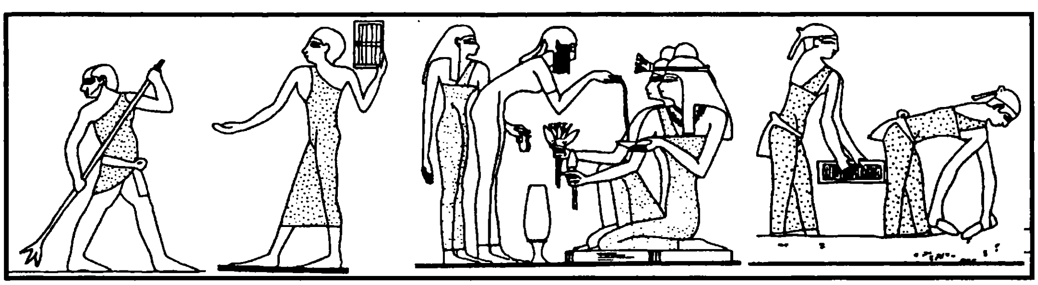


**Figure 4.12: Females with short skirts (top) and male and females with wrap-around garments (bottom).**
Adapted from Vogelsang-Eastwood, G. 1992a: 15, 22, 24-25.


**Figure 4.13: Twenty variations of complex wrap-around garments worn by males and females in the Ramesside period.**
After Hofmann and Hofmann 2004: 167-168

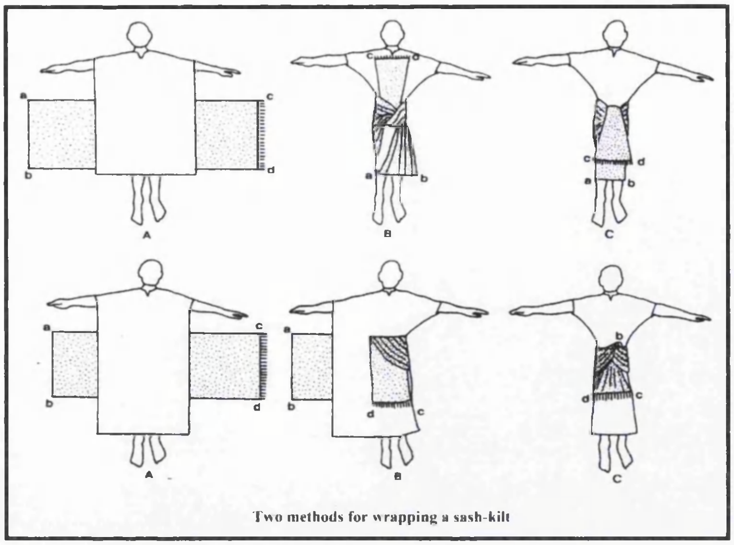



**Figure 4.14: Suggested methods of wrapping a rectangular area of cloth to produce a complex wrap-around sash kilt.**
After Vogelsang-Eastwood: 1992: 19.

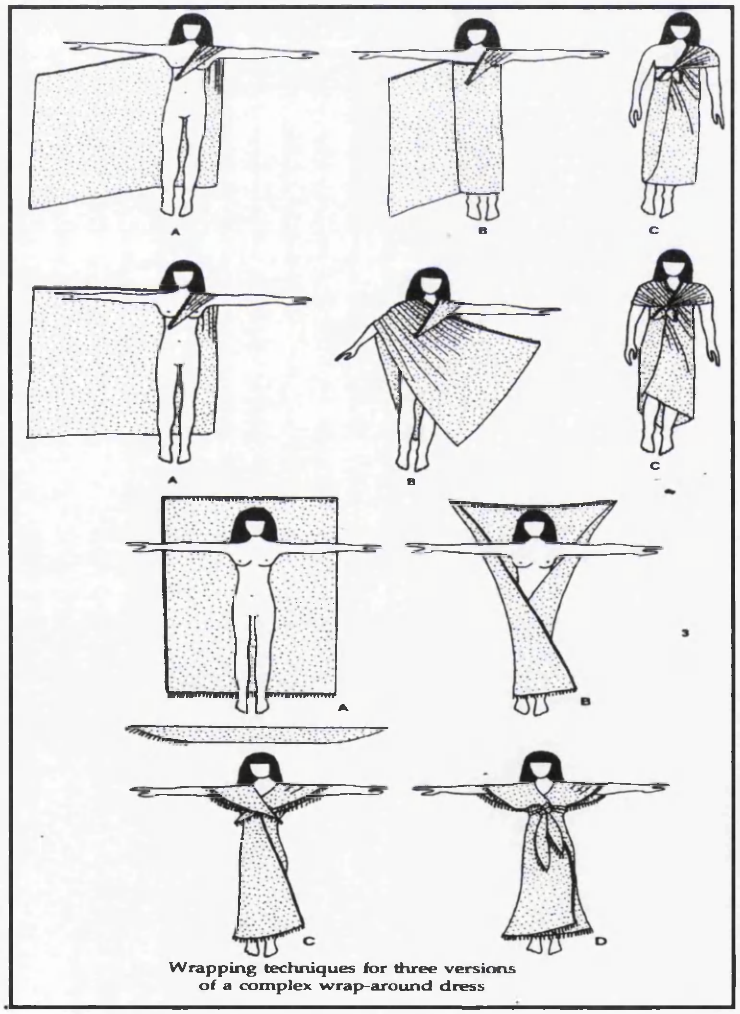



**Figure 4.15: Suggested methods of wrapping a rectangular area of cloth to produce a complex wrap-around style of dress.**
After Vogelsang-Eastwood: 1992: 29.

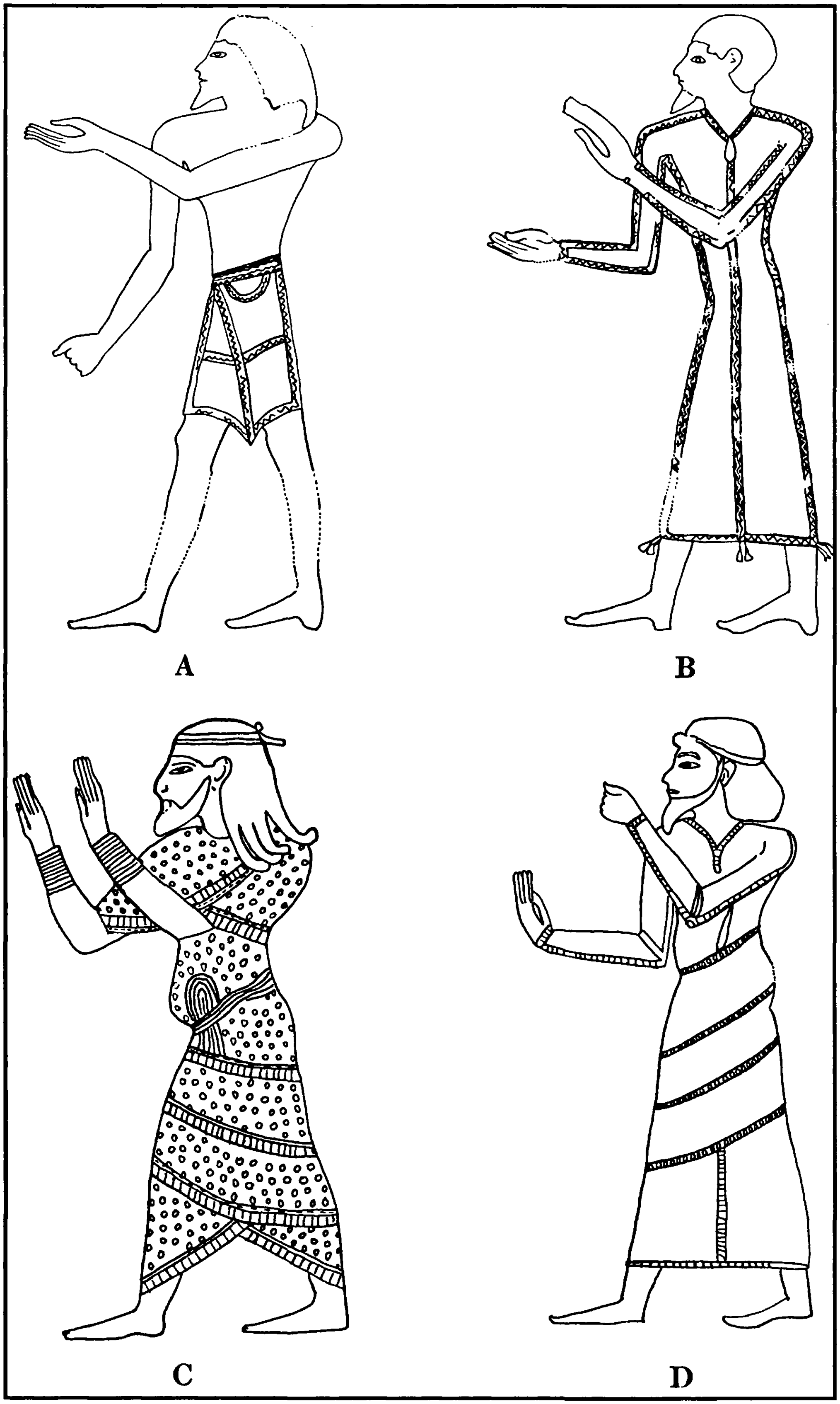
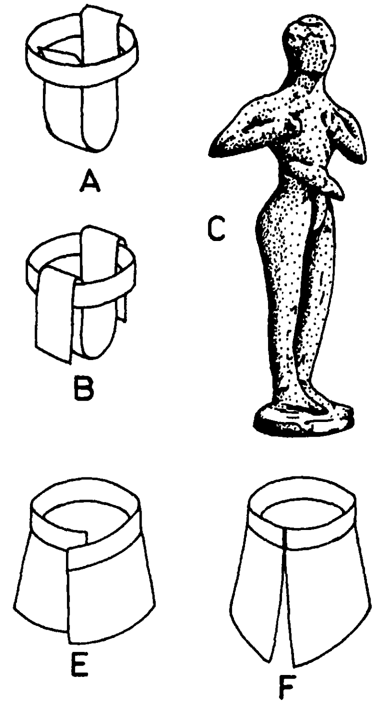
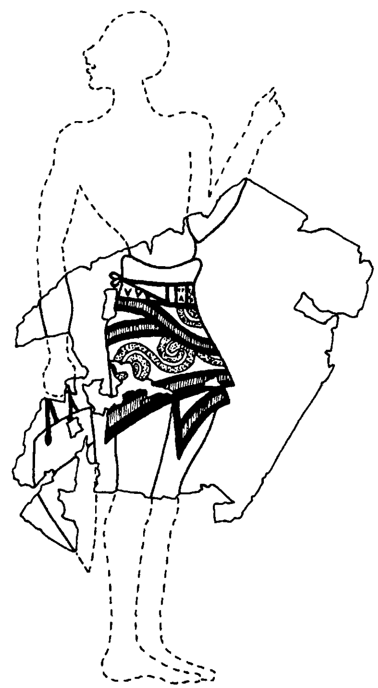


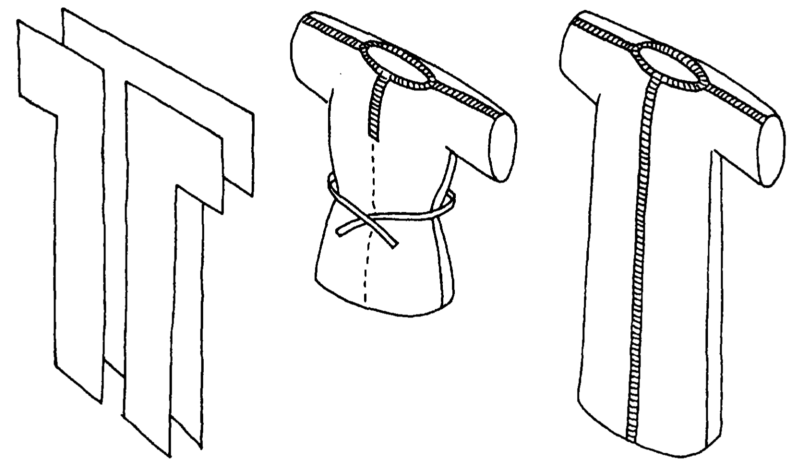

**Figure 4.16: Egyptian representation of Syrian prisoners wearing a range of garments.**
After Pritchard 1951: 39.




**1.0 A –C are examples of Aegean loincloths and E-F are simple wrap round kilts.**
After Rehak 1996: 40, figure 2.



**2.0 Complex wrap-round kilt from a fresco at Xeste 3, Akrotiri**



**3.0 Mycenaean short and long bag tunics.**
After

**Figure 4.17: Aegean loincloths, kilts and tunics.**
Adapted from left Rehak 1996: 40, Figure 2, middle from Doumas 1980: Plate 138, and right Rehak: 42, Figure 2.

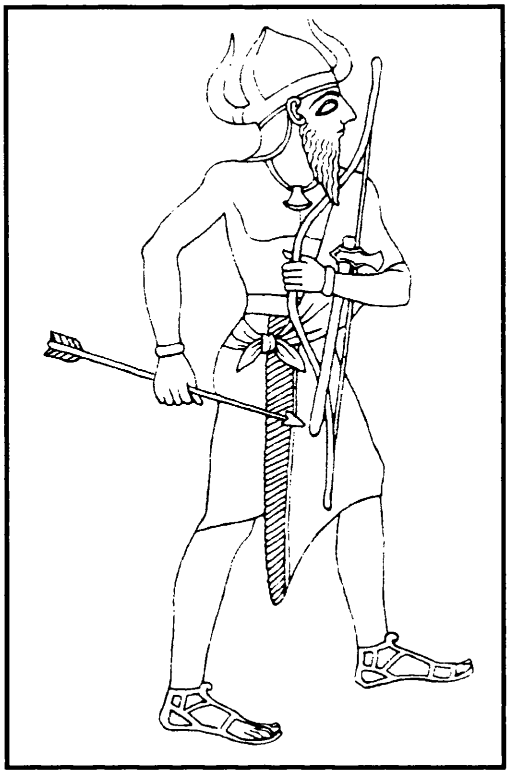


**Figure 4.18: Mesopotamian warrior ca. 2500 B.C., wearing a kilt and sash.**
After Houston 1954: 115, Figure 116.

**Figure 4.19: Huy, viceroy of Nubia, wearing a sash-kilt.**
After Vogelsang-Eastwood 1993: 68, Figure 4.22.

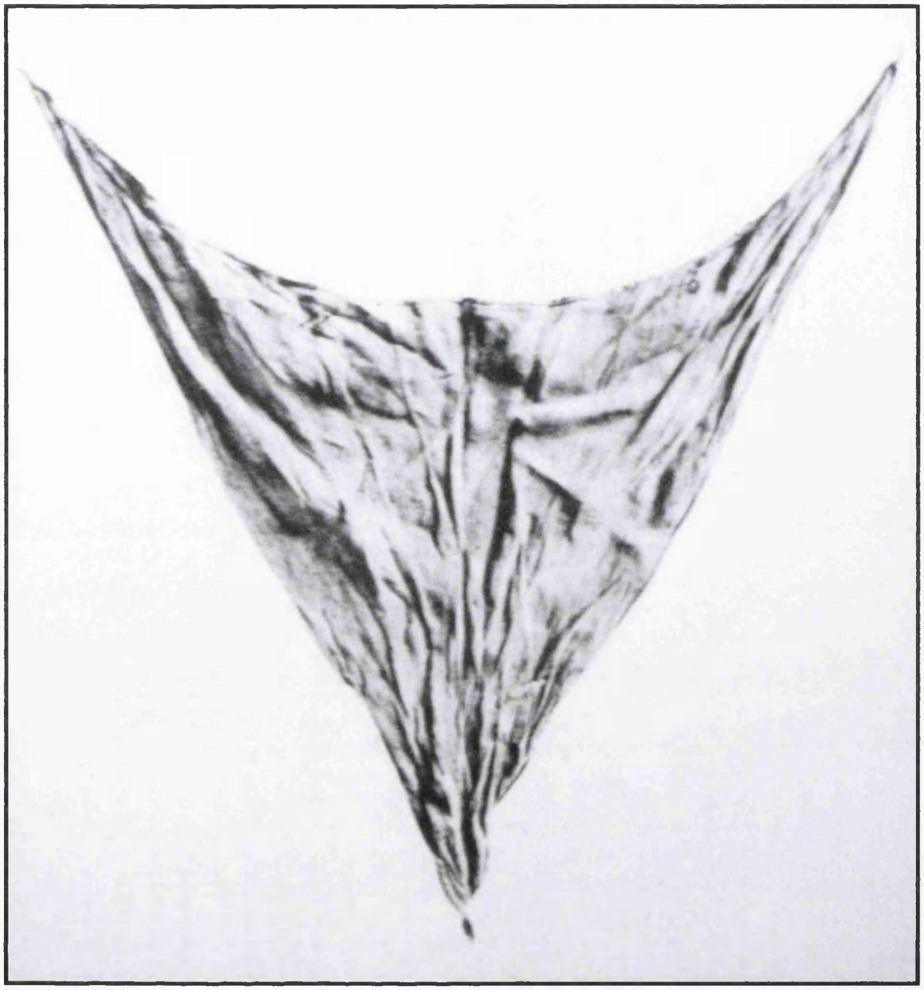


**Figure 4.20: Loincloth from the tomb of Kha and Merit. The top edge has been cut in a curve to ensure a tight fit to the waist.**
After Schiaparelli 1927: 90, Figure 62.

**Figure 4.21: Mesopotamian seal showing women with a flounced skirt with tiers of multicoloured stripes or fringes.**
After Jones 2005: Plate CLXXVIIIa.

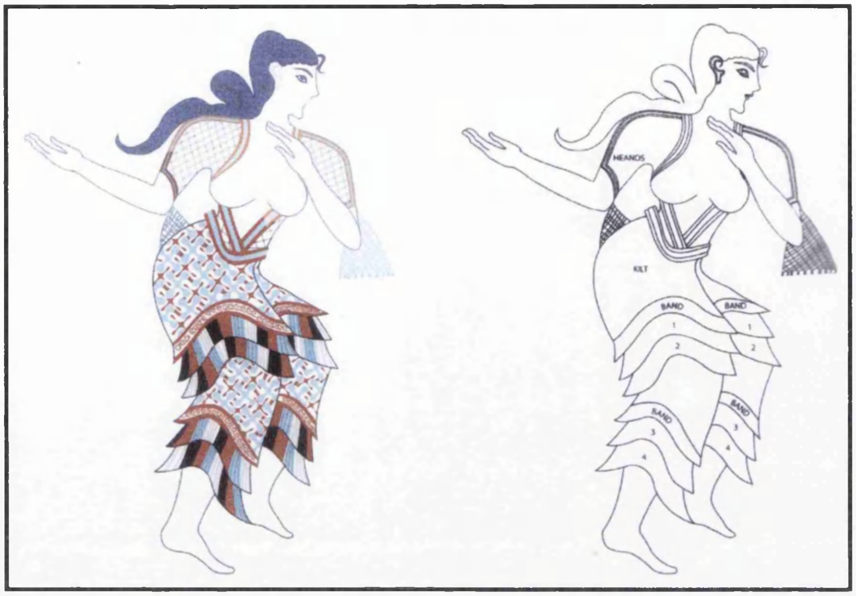


**Figure 4.22: Basic design of the flounced skirt, using Aegean evidence from a Late Minoan I fresco from the palace of Hagia Triada.**
After Jones 2005: Plates CLXXVIII.

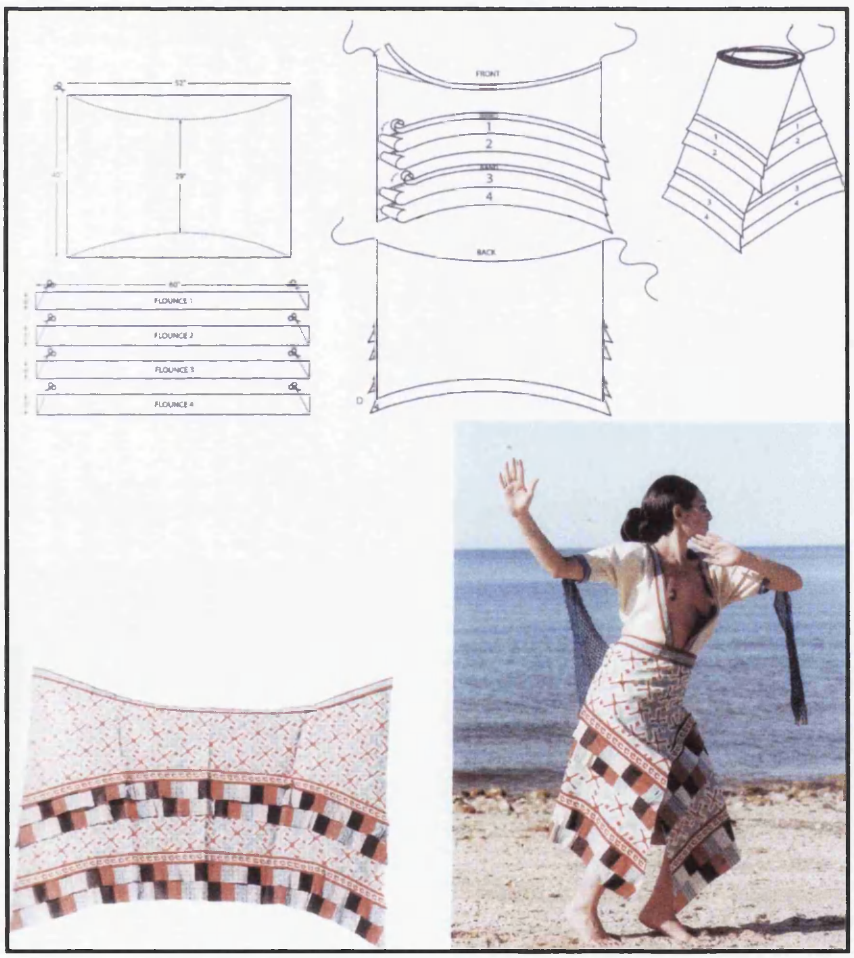


**Figure 4.23: Reconstruction of flounced skirt showing pattern and modelled garments.**
After Jones 2005: Plate CLXXIX.

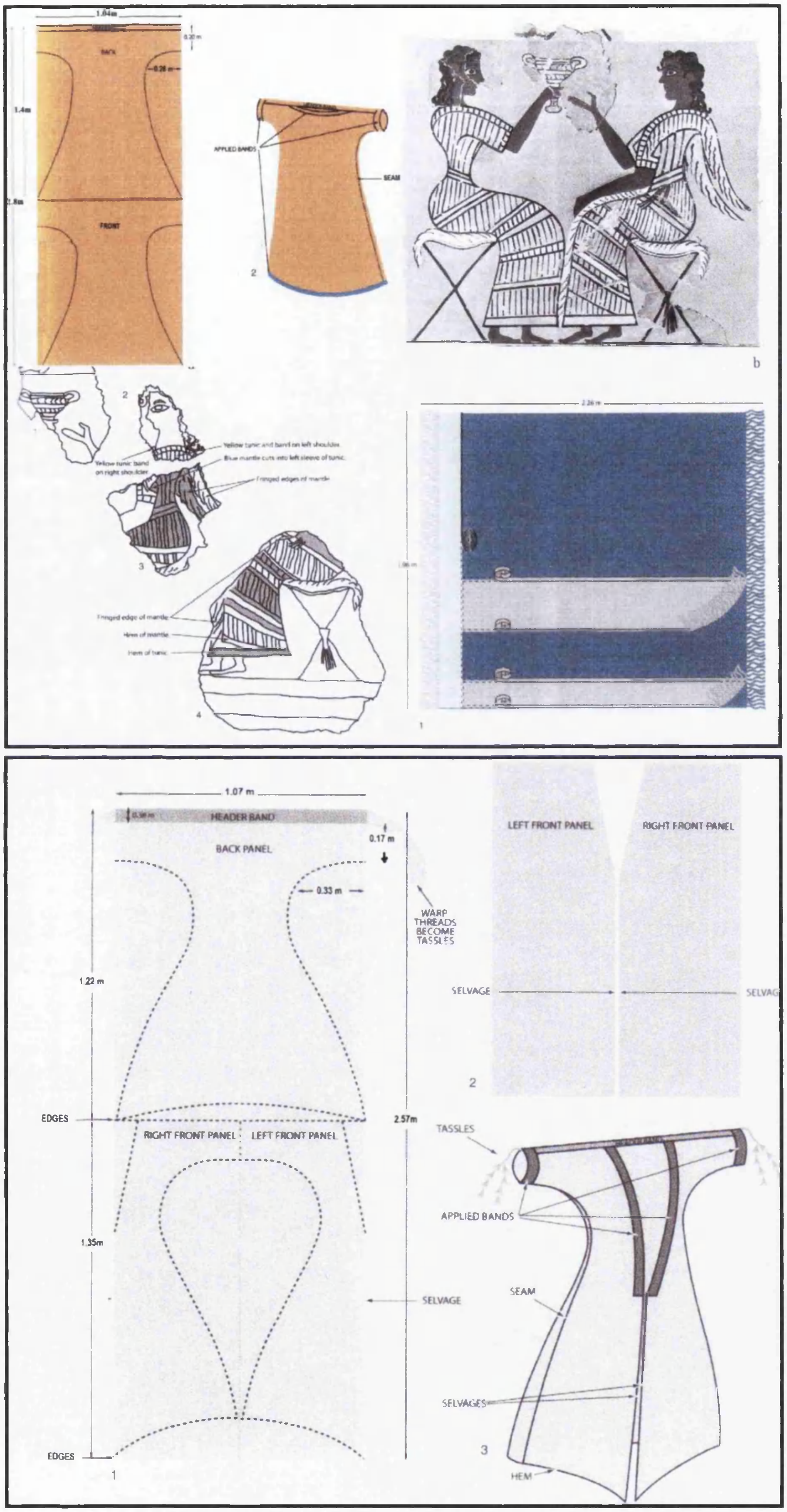



**Figure 4.24: Top - recreated tunic and bottom - pattern for V-neck dresses from Aegean frescoes.**
After Jones 2003, plates LXXXVI, LXXXVIII.

**Figure 4.25: Tunics, loincloths and sashes from the Tomb of Kha in Turin Museum.**
After Donaldson 1992: 33.

**Figure 4.26: Twenty-two assorted pieces of linen cloth.**
After Schiaparelli 1927: 95, Figure 66.

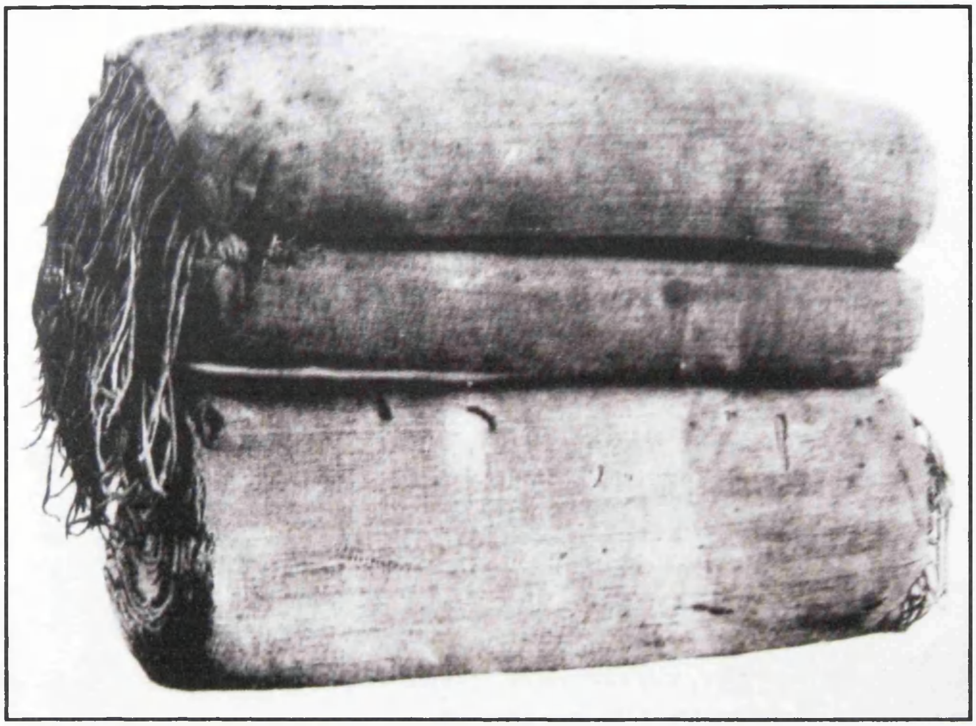


**Figure 4.27: Three bolts of fringed linen cloth.**
After Schiaparelli 1927: 98, Figure 70b.

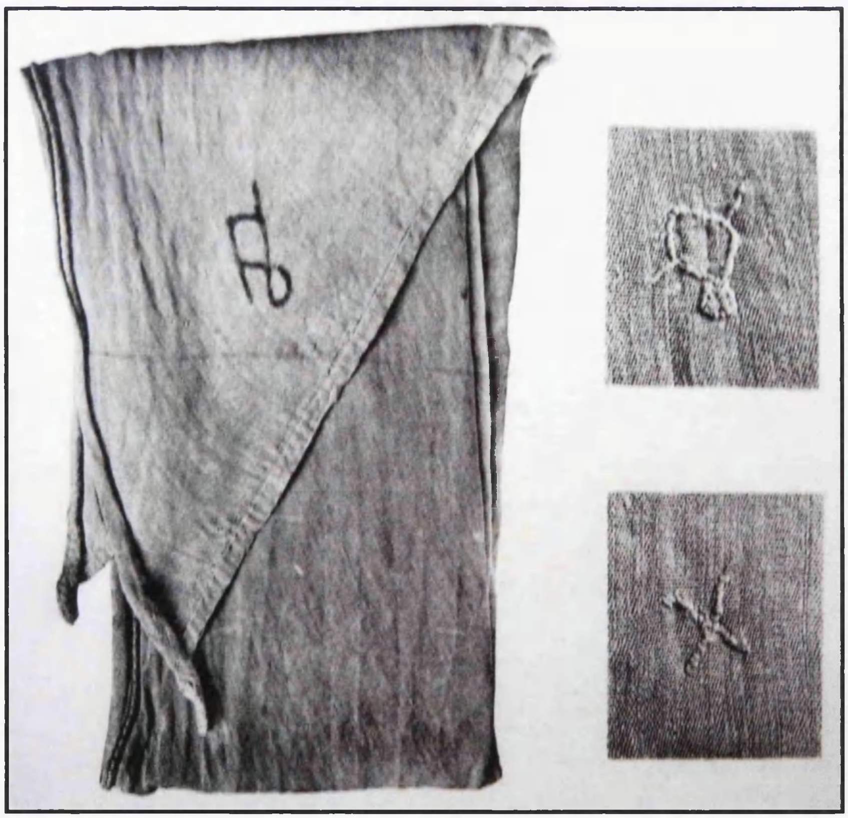


**Figure 4.28: Printed ink laundry marks and embroidered monograms of Kha's name.**
After Schiaparelli 1927: 99, Figure 71.

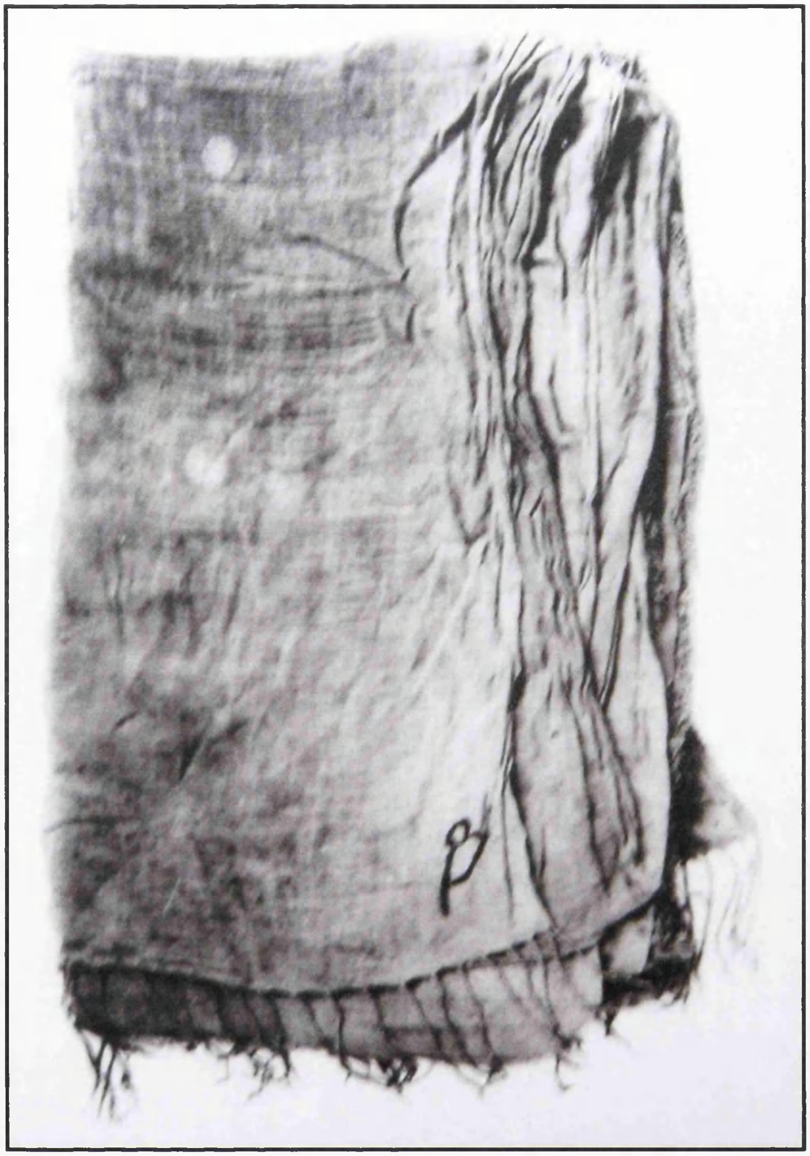


**Figure 4.29: Dressing gown of Merit with her own printed-ink laundry mark.**
After Schiaparelli 1927: 106, Figure 80.

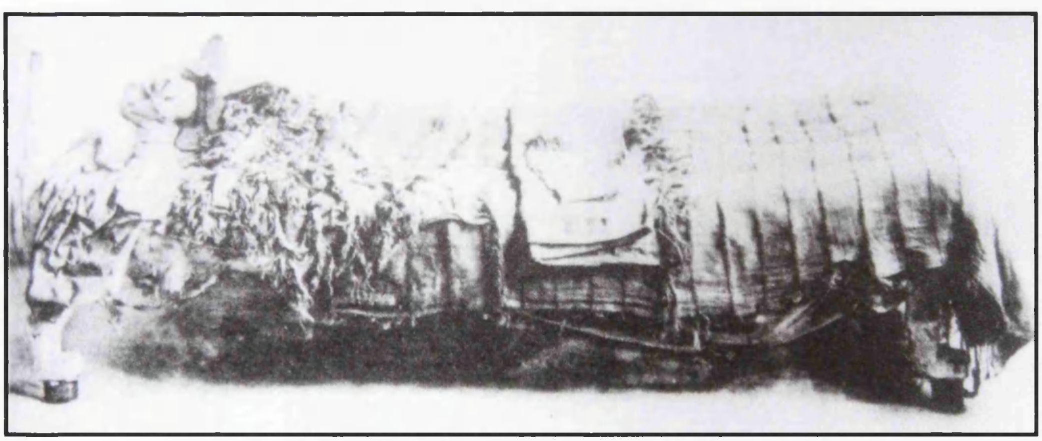


**Figure 4.30: Merit's bed covered in warm blankets and folded sheets.**
After Schiaparelli 1927: 129, Figure 105.

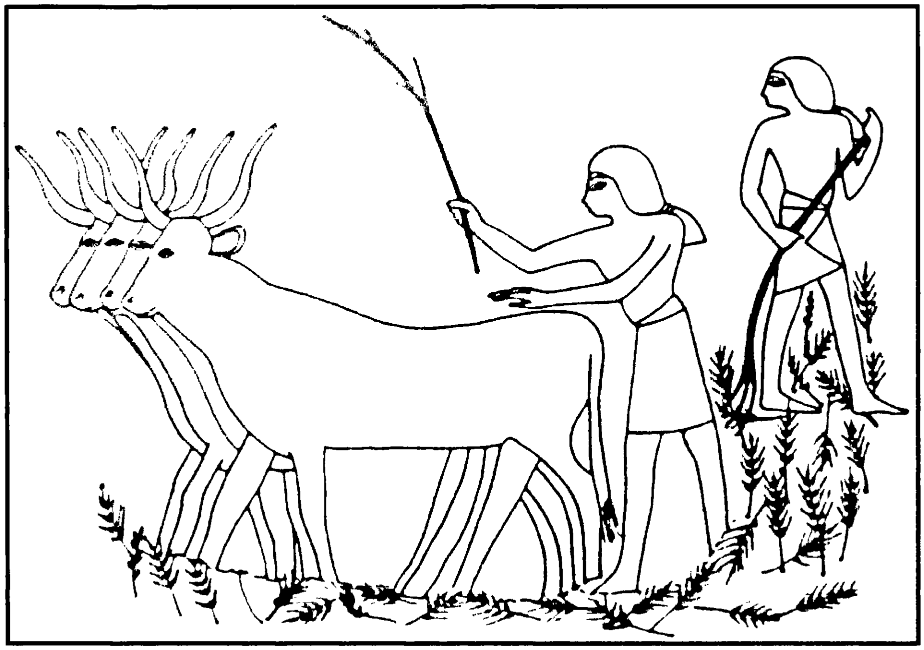


**Figure 4.31: Examples of kerchiefs, headgear fastened to the nape of the neck. New Kingdom, Tomb of Menna at Thebes (TT69).**
After Volgelsang-Eastwood 1993: 176, Figure 10.7.

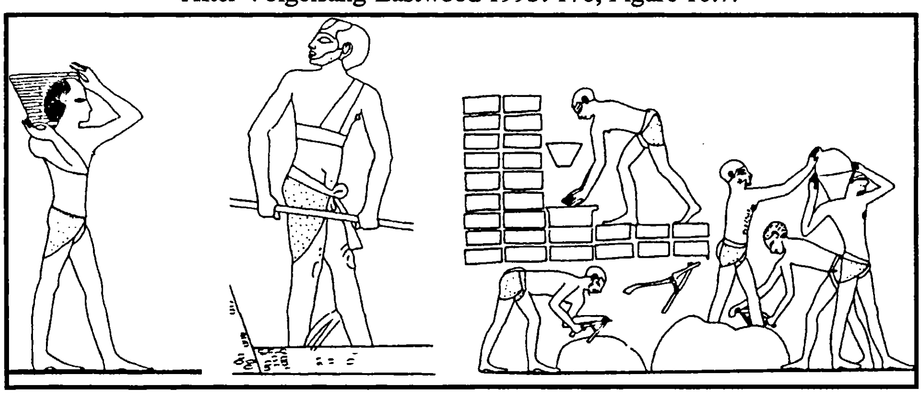


**Figure 4.32: Loincloths worn by manual workers. Left man wearing a closed loincloth, middle man an open loincloth fastened by a sash, and right workers with closed loincloths and sashes.**
Adapted from Volgelsang-Eastwood 1992a: 8.

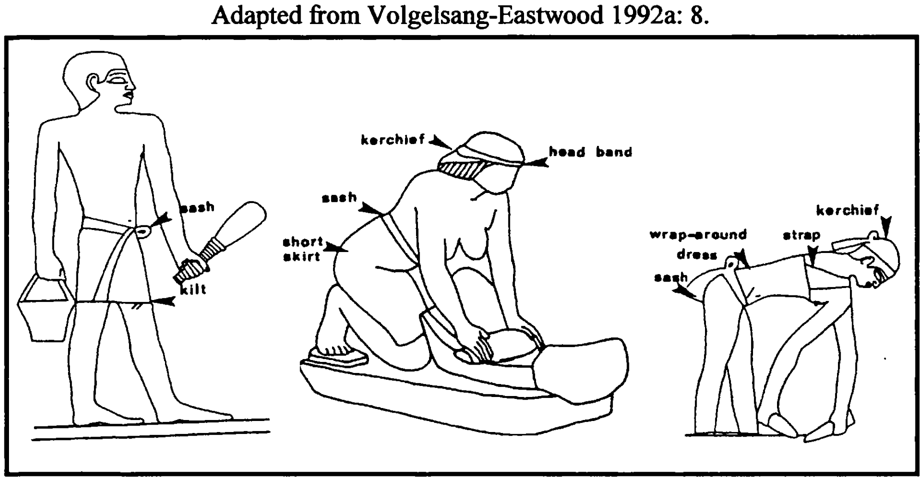



**Figure 4.33: Selection of garments worn by manual workers in pursuit of their duties.**
Adapted from Volgelsang-Eastwood 1992a: 48 and 49.

**Figure 4.34: Wrap-around cloaks, probably made of a course hessian weave as found at Amana, worn as a protection from dust storms and cold in winter.**
Adapted from Kemp, B.J. and G. Vogelsang-Eastwood. 2001: 237, Figure 6.70.

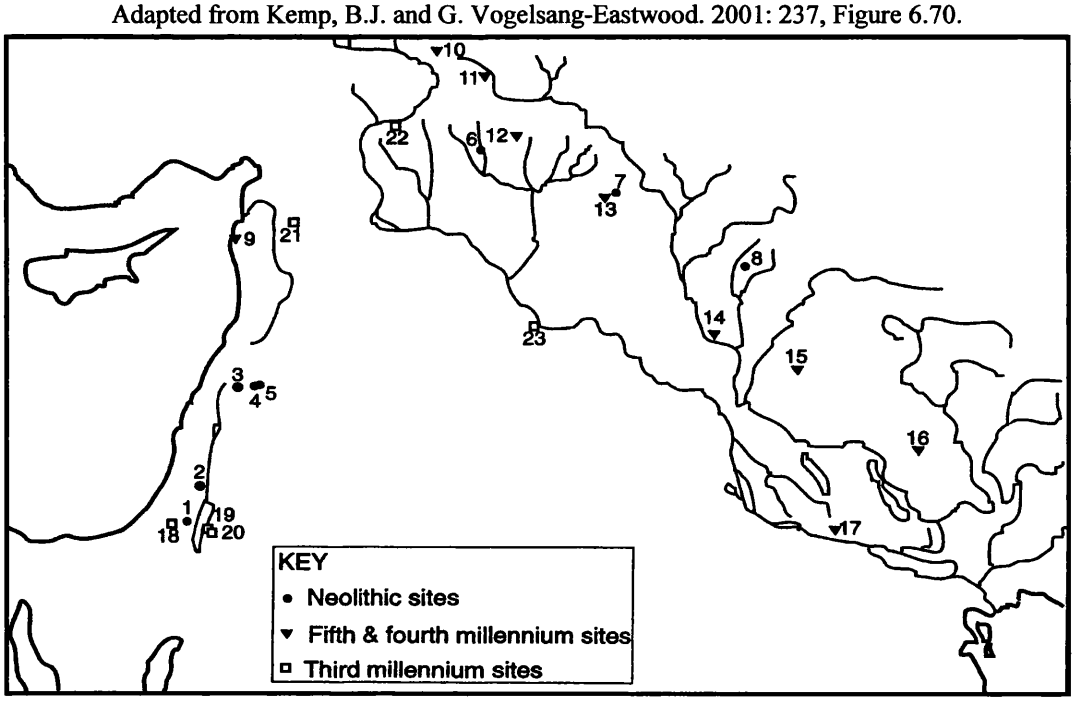



**Figure 4.35: Development of flax production in Anatolia, Mesopotamia and the Levant.**
After McCorriston 1997: 520, Figure 1.

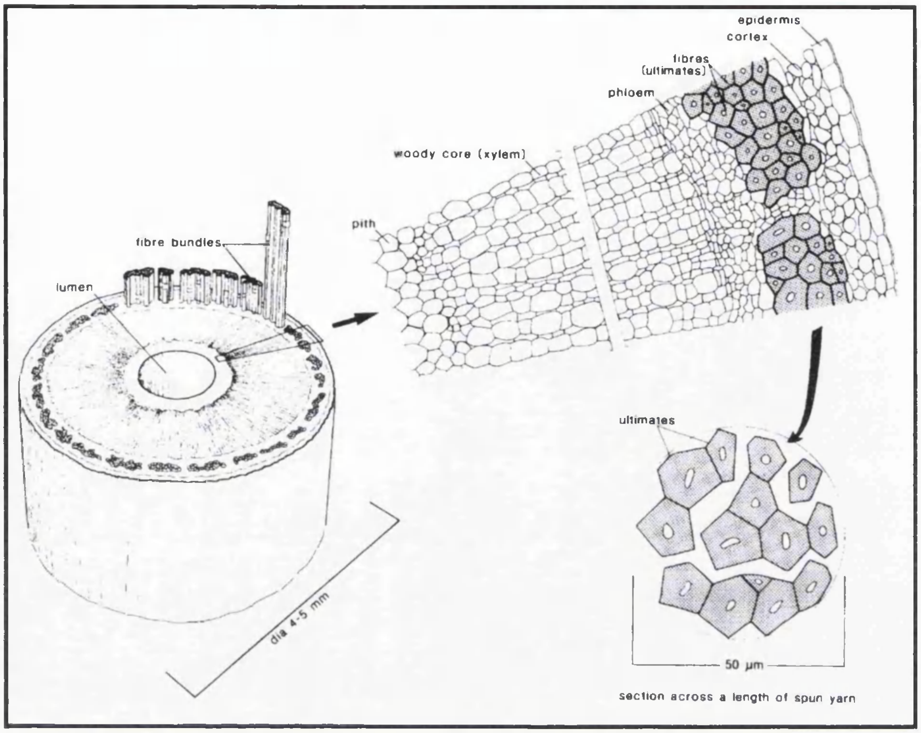



**Figure 4.36: Cross-section of the flax plant.**
After Kemp and Volgelsang-Eastwood 2001: 26, Figure 2.1.

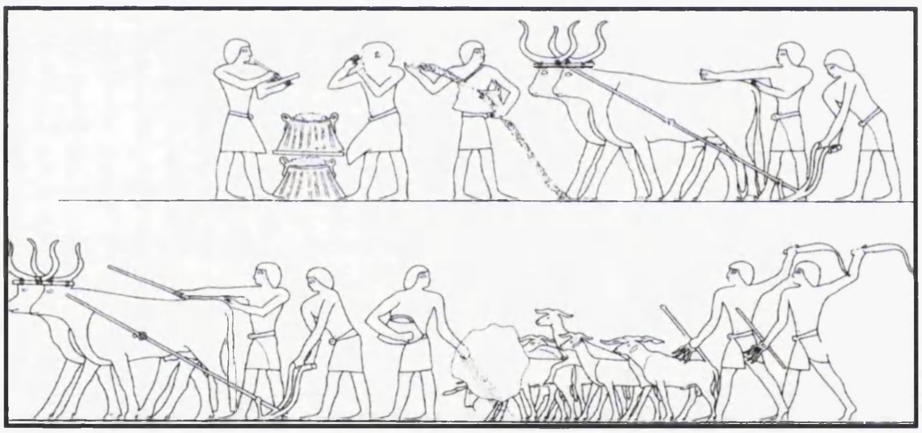


**Figure 4.37: Ploughing, sowing and trampling-in of flax seed, Middle Kingdom Tomb of Urarna at Sheike Saïd (Tomb 25).**
After Davies 1901: Plate XVI.

**Figure 4.38: Harvesting of flax, New Kingdom Tomb of Sennedjem at Deir el Medina.**
After Wilkinson 1979: 53, Figure 64.

**Figure 4.39: Tomb of Neferrenpet (TT 178), showing the transparency of the fine cloth.**
After Hofmann 1995: Plate IX.


**Figure 4.40: Removing seed heads, tying up bundles and carrying bales to the river for retting.**
**New Kingdom Tomb of Paheri at El Kab (Tomb EK3).**
Adapted from Tylor 1895: Plate III.

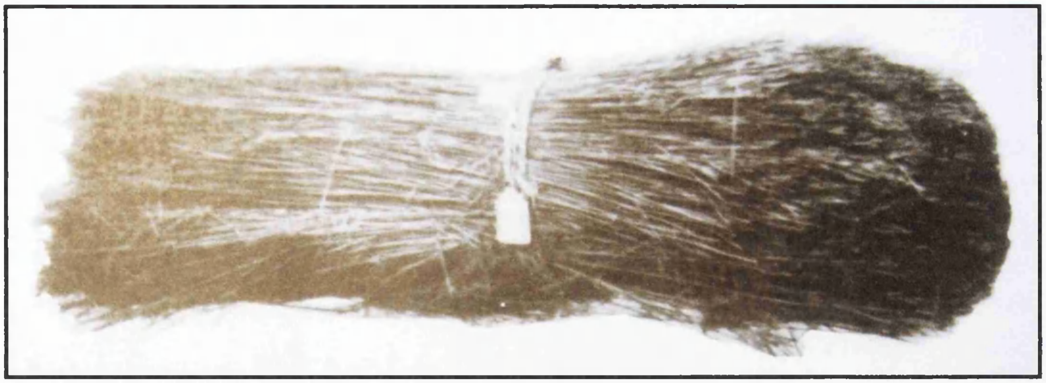


**Figure 4.41: Ancient bale of flax preserved in the Doqqi Agricultural Museum in Cairo.**
After Brewer 1994: 19, Figure 4.2.

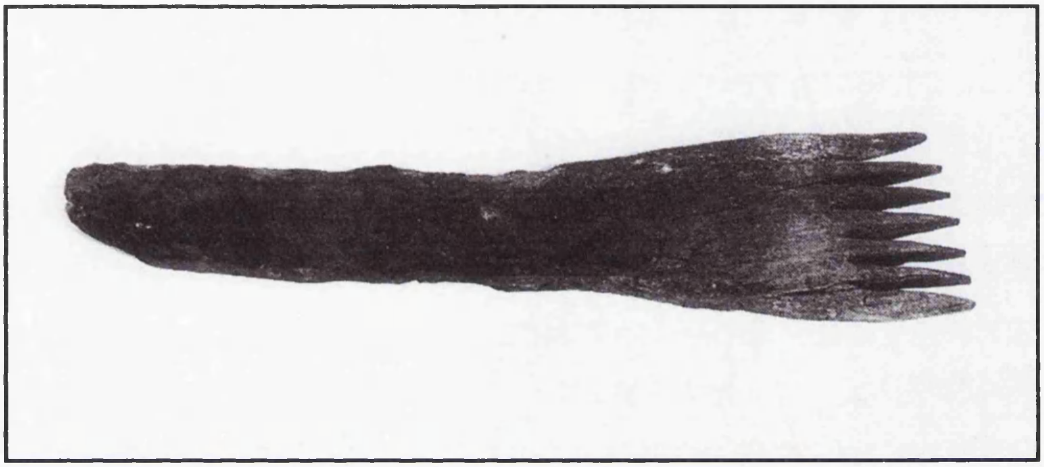


**Figure 4.42: Wooden comb used to remove seed bolls from flax stalks, Kahun Middle Kingdom. Manchester University Museum 6859.**
After Volgelsang-Eastwood 1994: 19.

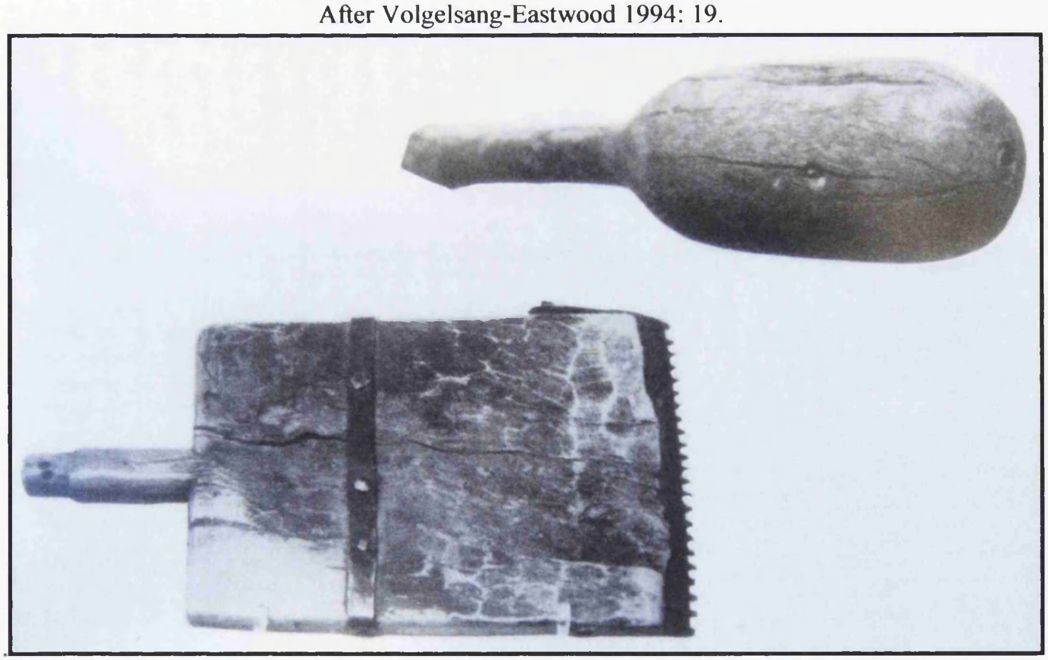


**Figure 4.43: Ancient mallet, thought to have been used for beating flax and comb to separate and clean the flax fibres. On display at the Doqqi Agricultural Museum in Cairo (provenance unknown).**
After Brewer et al 1994: 37, Figures 4.4.

**Figure 4.44: Ethnographic evidence from Egypt of using a mallet for scutching flax**
After Crowfoot 1931: Plate 19.


**Figure 4.45: Flax preparation: separating the fibres of flax from the stalks, splicing them into long continuous threads and spinning two threads to produce two-ply thread ready for weaving. Twelfth Dynasty Tomb of Daga at Thebes (TT 103).**
Adapted from Barber 1991: 45, Figure 2.5.

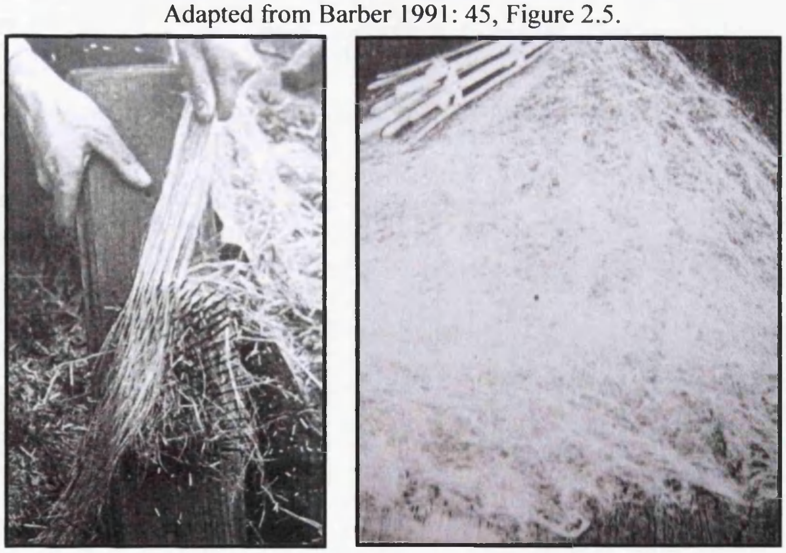


**Figure 4.46: Separating flax by combing (hackling) flax fibres. The next photograph shows the fineness of flax possible using this method.**
After Leadbeater et al 1976: 61-62, Figures 4.2 and 4.3.

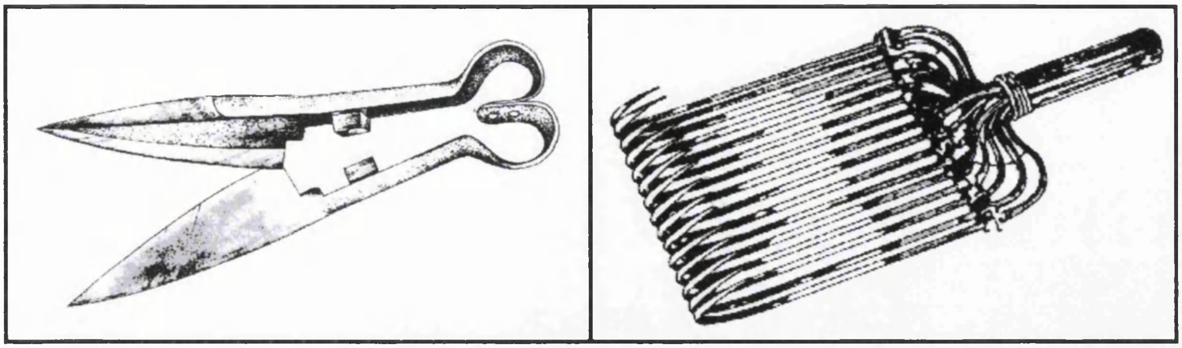


**Figure 4.47: Hand shears and wool-plucking comb. The operation of both tools requires a spring action to operate effectively.**
After Petrie 1995: Chapter 3, Figures 3.5-3.6.

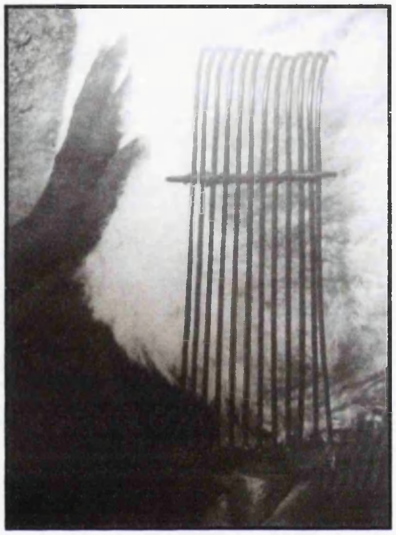


**Figure 4.48: Using a metal comb to comb out the wool from a cashmere goat**
After Melena 1975: 417.

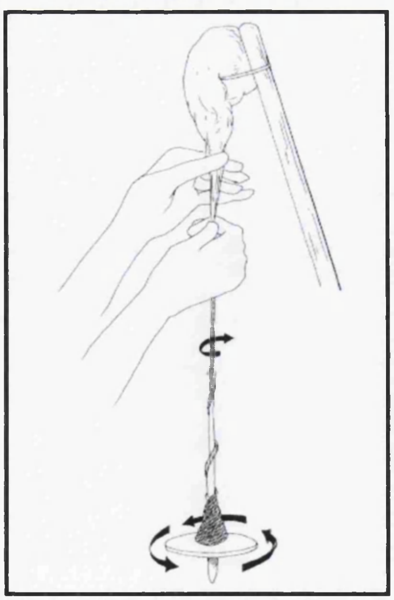


**Figure 4.49: The spinner draws down fibre into a thread from a relatively large fibre source. The action of turning of the spindle adds twist to the yarn.**
After Tiedemann and Jakes 2006: 296, Figure 2.

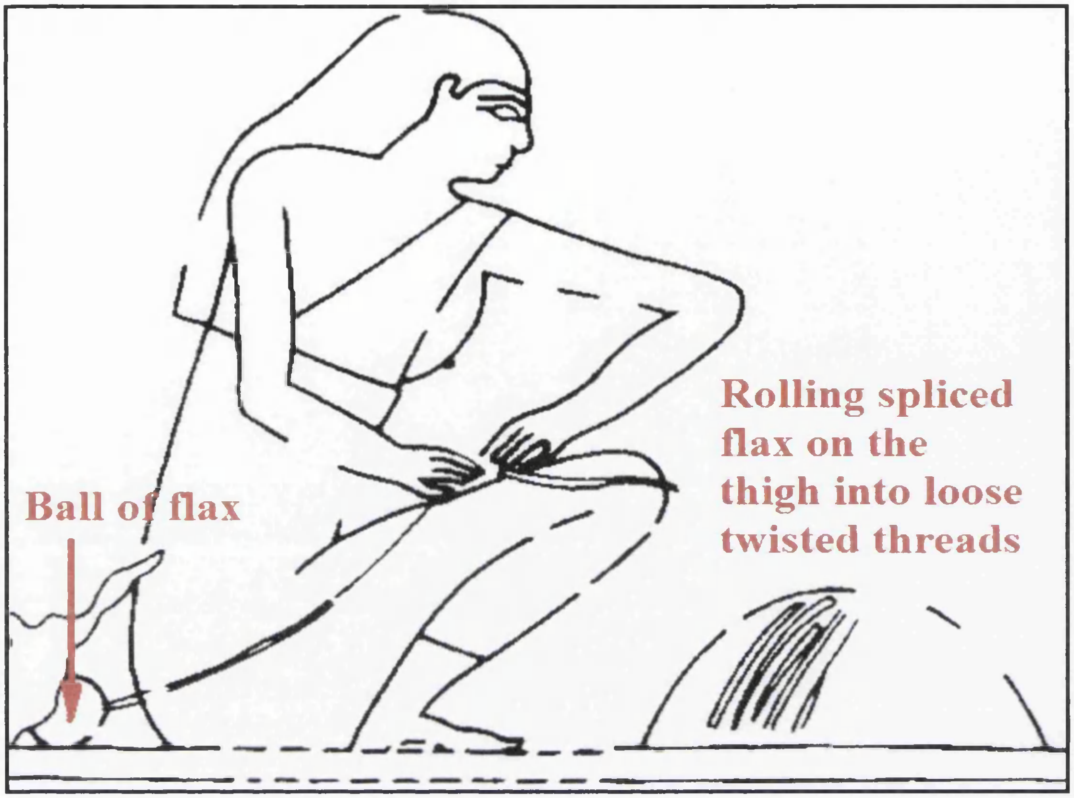



**Figure 4.50: Thigh spinning of spliced flax into a ball of loose twisted threads. Close-up of the Twelfth Dynasty Tomb of Daga at Thebes (TT 103).**
Adapted from Barber 1991: 45, Figure 2.5.

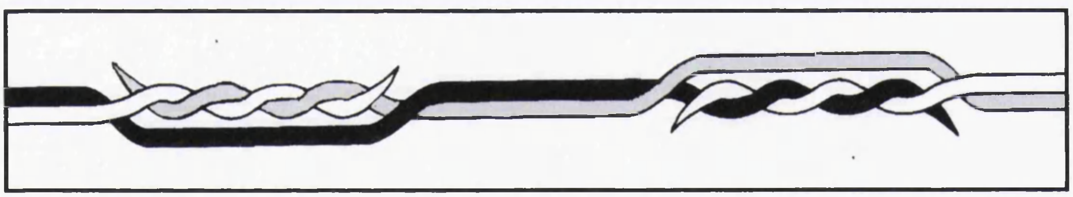


**Figure 4.51: Two-ply yarn showing the Egyptian method of splicing flax fibres. Note that the spliced joints are never consecutive.**
Adapted from Barber: 47, Figure 2.9.

**Figure 52: Spliced linen flax, enlarged x18. Sample taken from the shroud of Tny, 18th Dynasty.**
After Jones 2006: Plate 59. Photograph R. Oldfield.

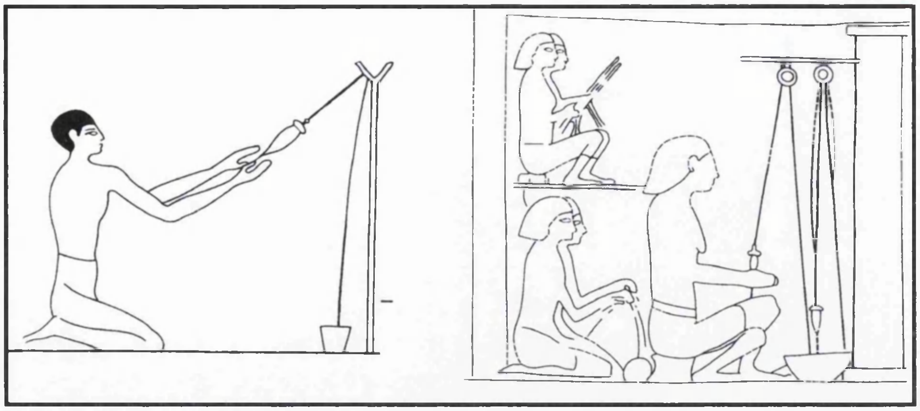


**Figure 4.53: Simple and more complex forms of spinning spliced flax. Left - Middle Kingdom, Tomb of Khety at Beni Hassan (BH17) and right - New Kingdom, Tomb of Thutnefer at Thebes (TT104).**
After Vogelsang-Eastwood 2000: 273, Figures 11.4a and 11.4b.

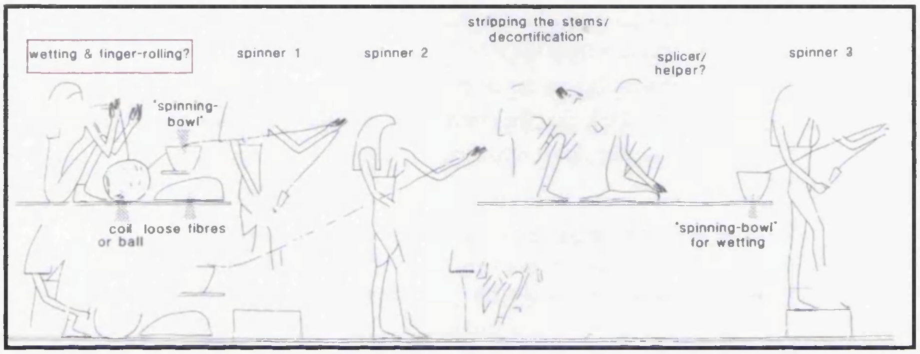



**Figure 4.54: Possible moistening of fibres in the mouth from the tomb of Khety at Beni Hasan (Newberry [1895]: pl. XXVI).**
After Kemp and Volgelsang-Eastwood 2001: 69, Figure 3.13.

**Figure 4.55: Ethnographic evidence of flax fibres moistened in the mouth in the spinning process.**
After Crowfoot 1931: Plate 22.

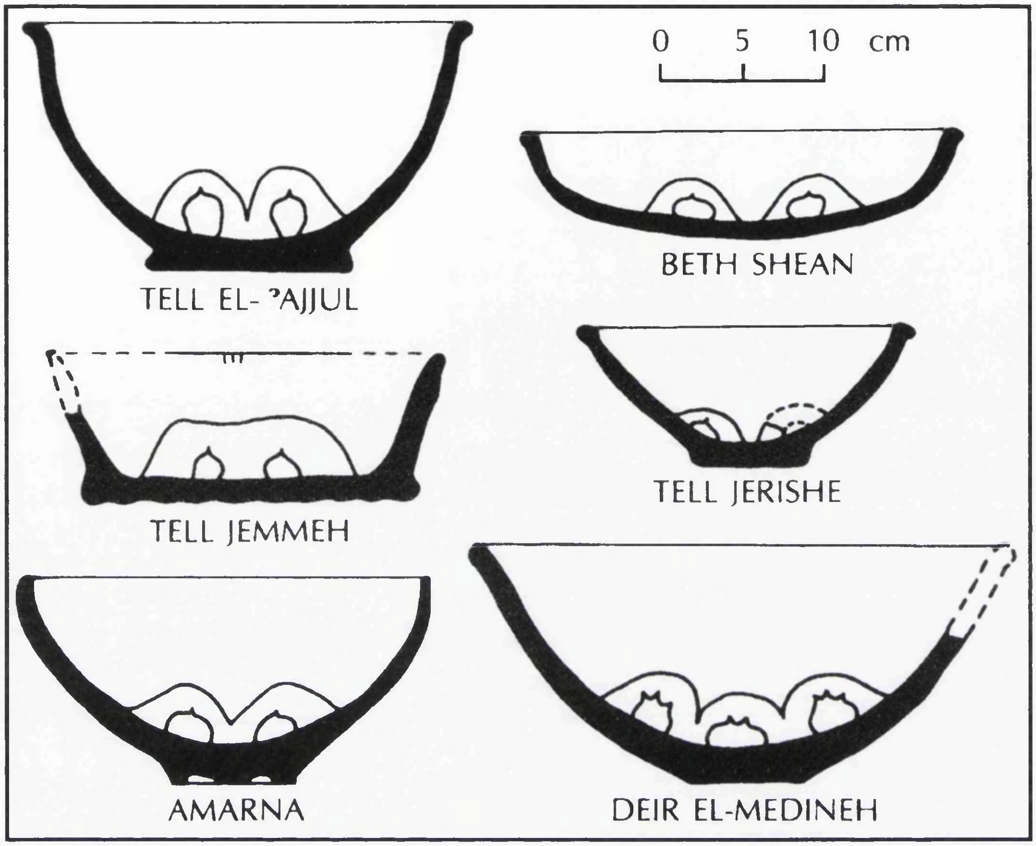



**Figure 4.56: Clay bowls with internal loops, possibly also filled with water when spinning flax.**
After Dothan 1963: Figures 1.3.

**Figure 4.57: Two forms of an Egyptian spindle and a wooden netting needle. Petrie Museum, references top to bottom UC7306ii from Kahun and UC7809, UC7806 from Gurob.**
After Quirke 2003.

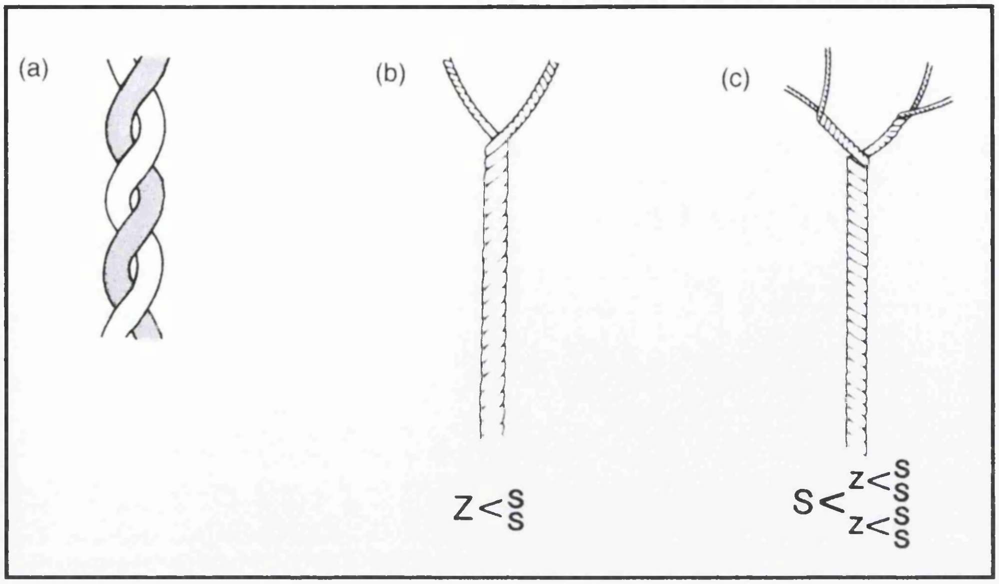



**Figure 4.58: (a) Two threads are spun in a clockwise Z direction (b) Two Z plied yarns made with two anticlockwise yarns (c) Four s-spun threads are Z plied into two twisted pairs, and the two pairs are S-plyed together.**
After Kemp and Vogelsang-Eastwood 2001: 58, Figure 3.2.

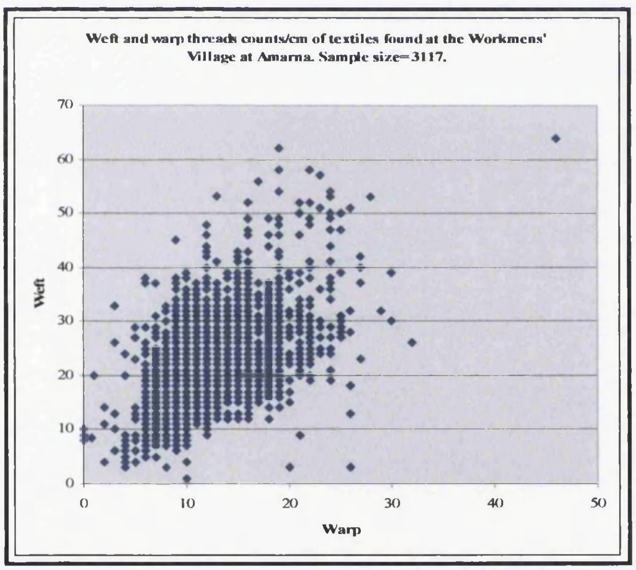



**Figure 4.59: Scatter chart of the weft and warp counts/cm from 3117 samples found in the Workmen's village at Amarna.**
After Kemp and Vogelsang-Eastwood 2001: 100, Figure 4.11.

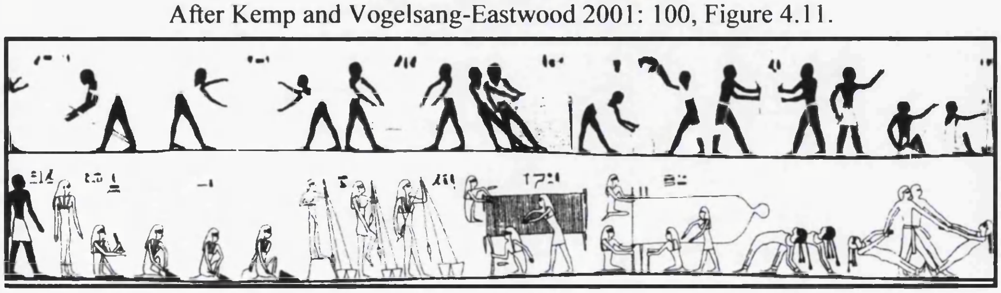


**Figure 4.60: Top register shows men washing cloth after weaving, and bottom register women spinning and weaving on ground looms. Tomb of Baqt at Beni Hasan (BH15).**
After Barber1991: 45, Figure 2.5.

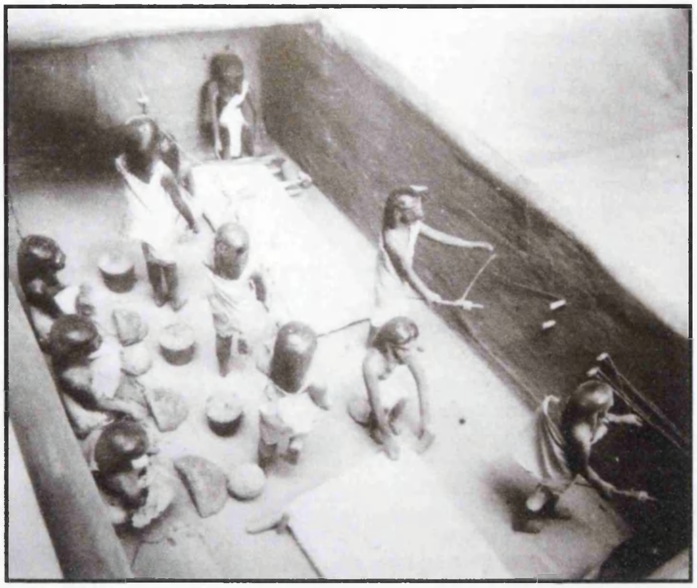


**Figure 4.61: Egyptian funerary model of textile workers using horizontal looms, from the Eleventh Dynasty Middle Kingdom tomb of Meket-Re (JE 46723. Egyptian Museum. Cairo).**
After Hall: 17, Figure 7.

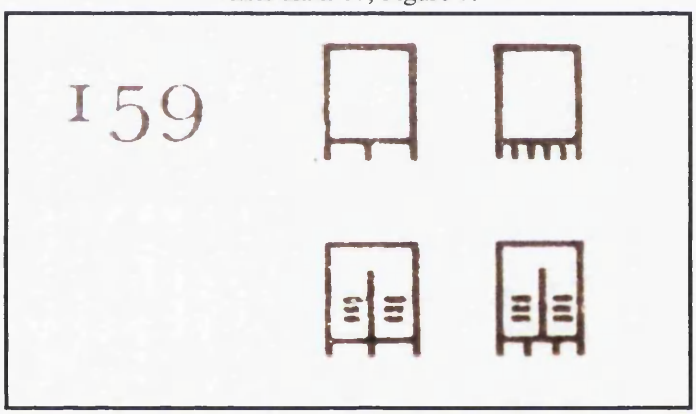



**Figure 4.62: Variations of the Mycenaean ideogram *159, thought to represent a vertical loom**
After Ventris and Chadwick 1973: 313.

**Figure 4.63: Three weavers using the same horizontal loom in Hebron.**
After Schick 1998: Plate 3.12

# Chapter 5 Figures: Shelter

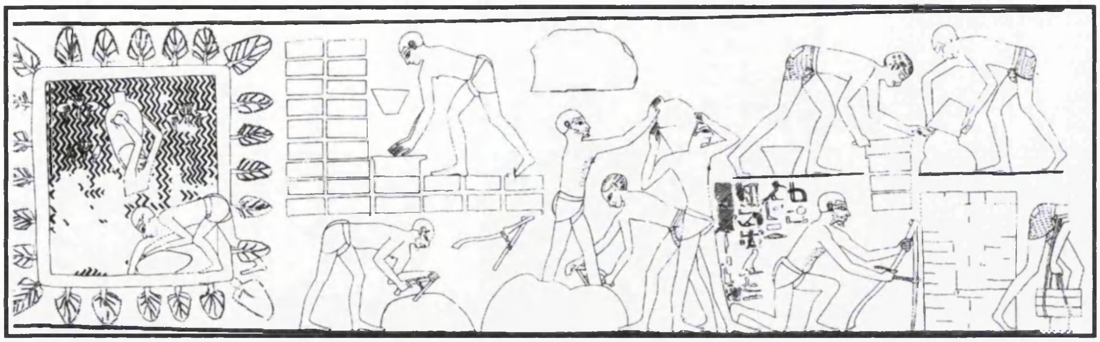


**Figure 5.1: Wall painting from the Tomb of Rekhmire illustrating the mud production process in the LBA.**
Adapted from Davies 1973 PL LVIII.

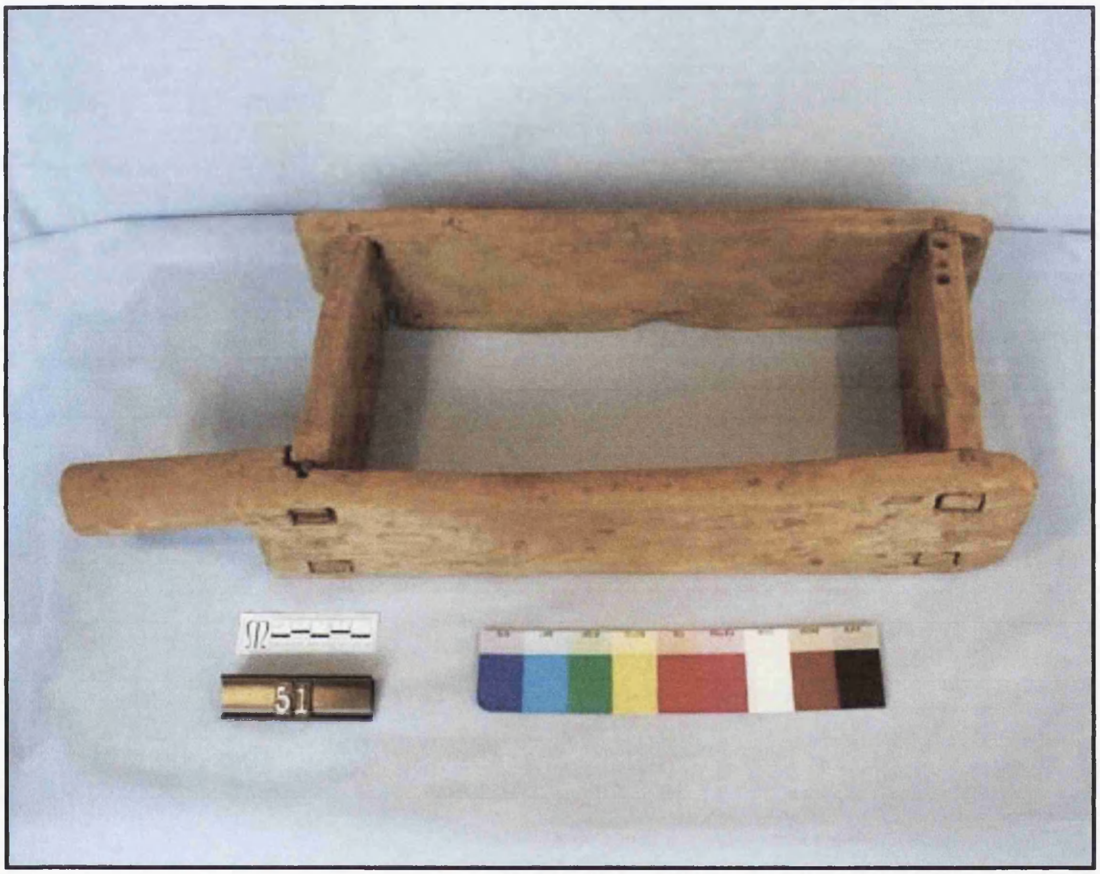



**Figure 5.2: Wooden mud brick mould from Kahun.**
The online entry for this object, accession number 51 may be accessed from http://emu.man.ac.uk/mmcustom/Display.php?irn=320832&QueryPage=%2Fmmcustom%2FEgyptQuery.php. Accessed 17th April 2008.

**Figure 5.3: Ramesseum granary on the West Bank of the Nile at Thebes.**
Photograph source unknown.

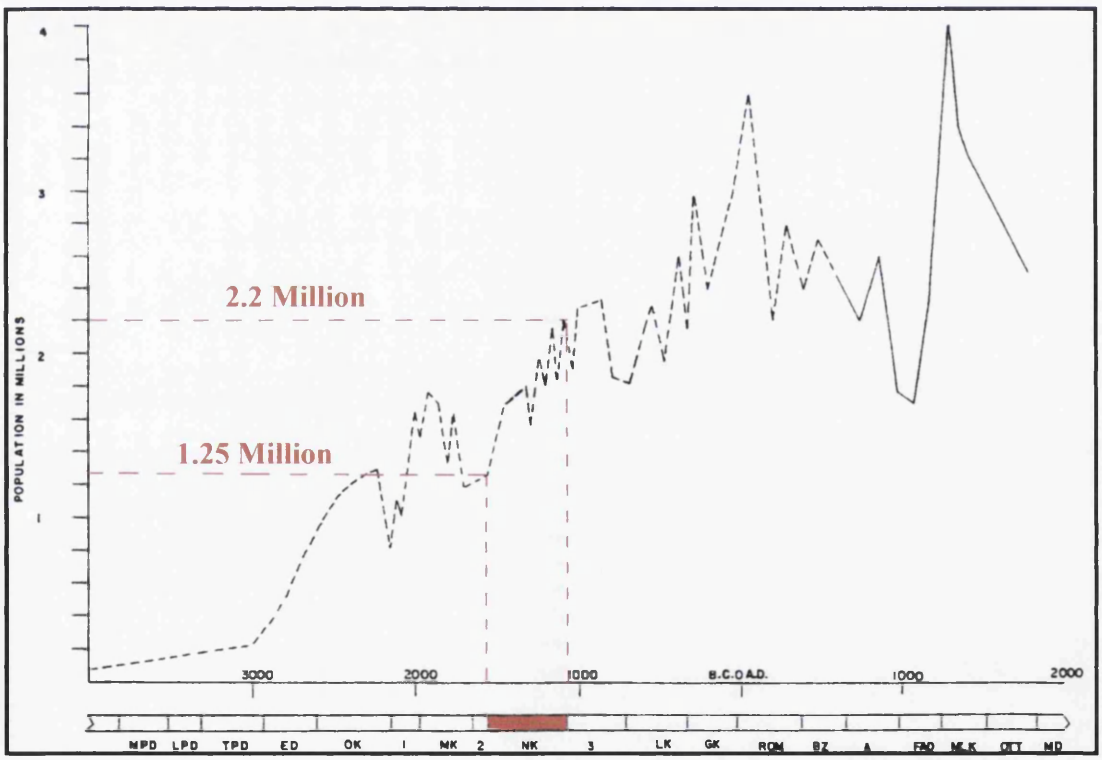



**Figure 5.4: Population growth of Egypt.**
Adapted from Hassan 1994: 171, Figure 7.1.

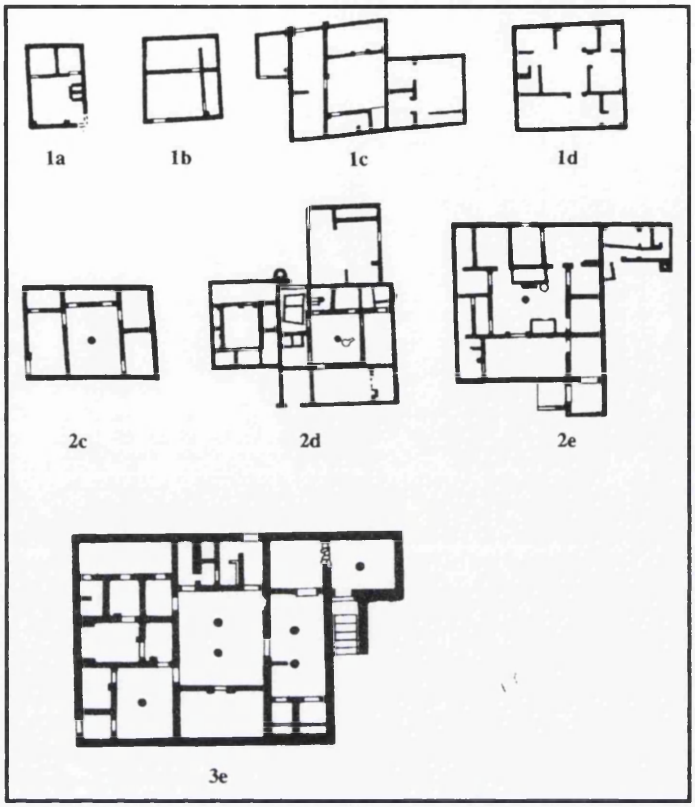



**Figure 5.5: Tietze's typology of Amarna domestic housing.**
After Lacovera 1997: 155, Figure 62.

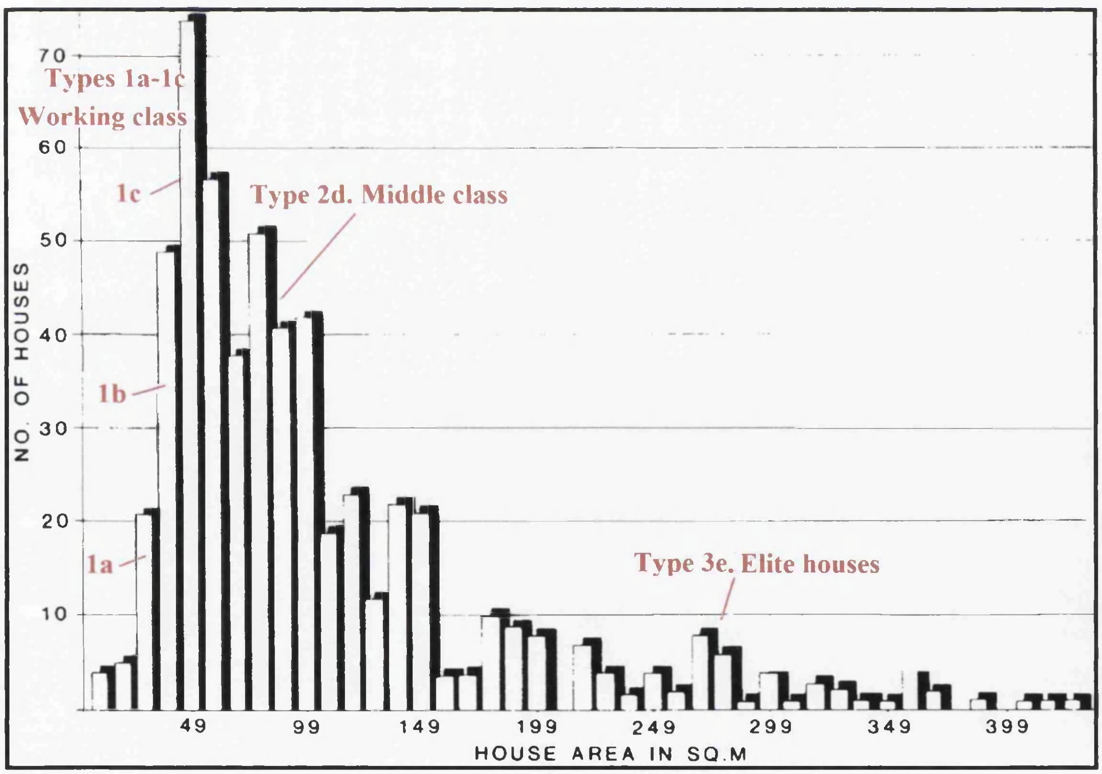



**Figure 5.6. Tietze's typology superimposed on a histogram of the frequencies of houses collated by floor area excavated within central Amarna. The histogram is after Piers Crocker, unpublished dissertation, University of Cambridge.**
Adapted from Kemp 2000: 300, Figure 101.

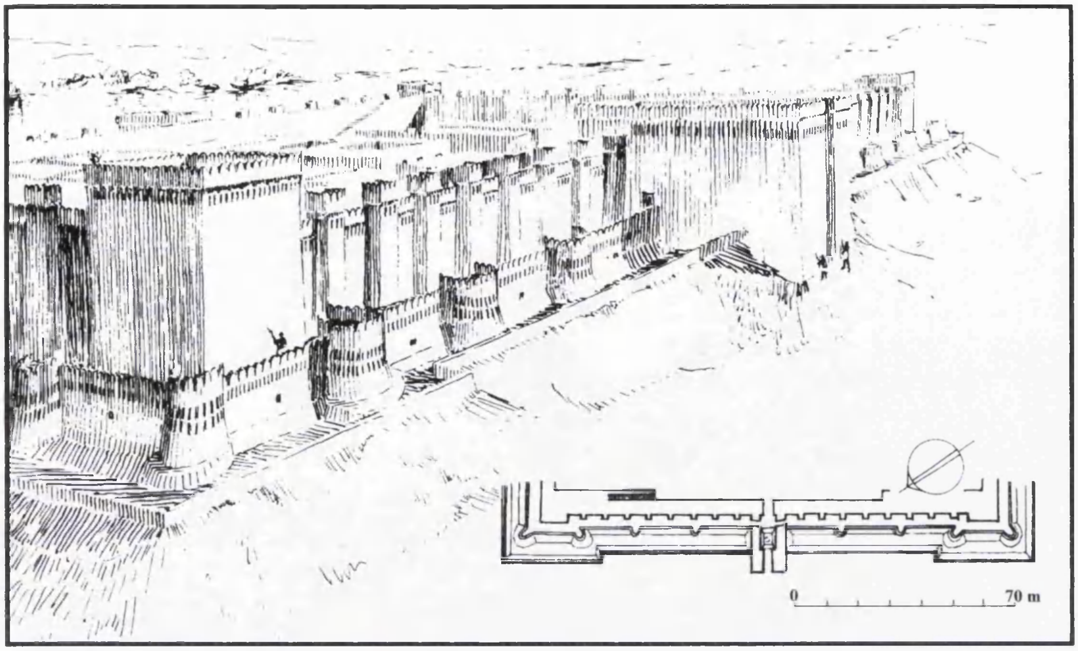



**Figure 5.7: Artist's impression of the scale of the Middle Kingdom fortress at Buhen.**
After Badawy 1966: 213, Figure 97.

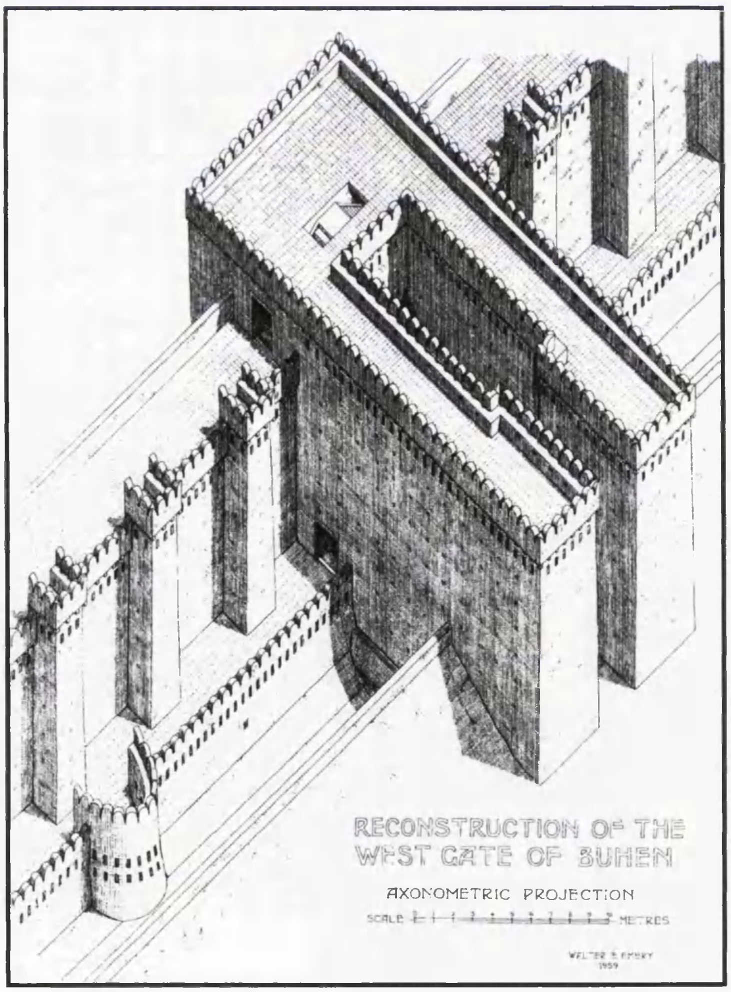



**Figure 5.8: Scale drawing of the mud brick west gate of Buhen.**
After Emery 1979: Plate 11.

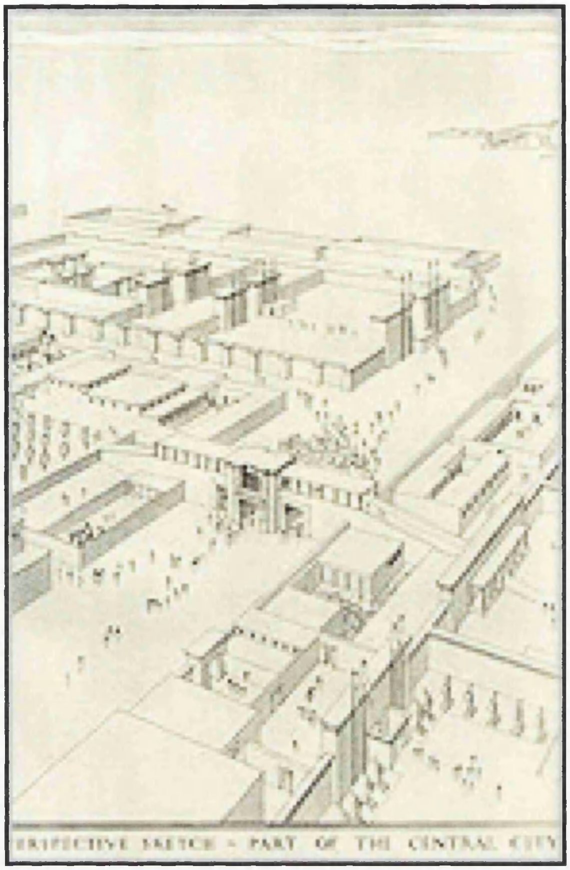


**Figure 5.9: Artistic image and scale model of the administration buildings in central Amarna.** After Kemp 2001, Amarna Project, Accessed 21st April 2008, Last Update January 2008. Available from http://www.amarnaproject.com/pages/amarna_the_place/central_city/index.shtml.

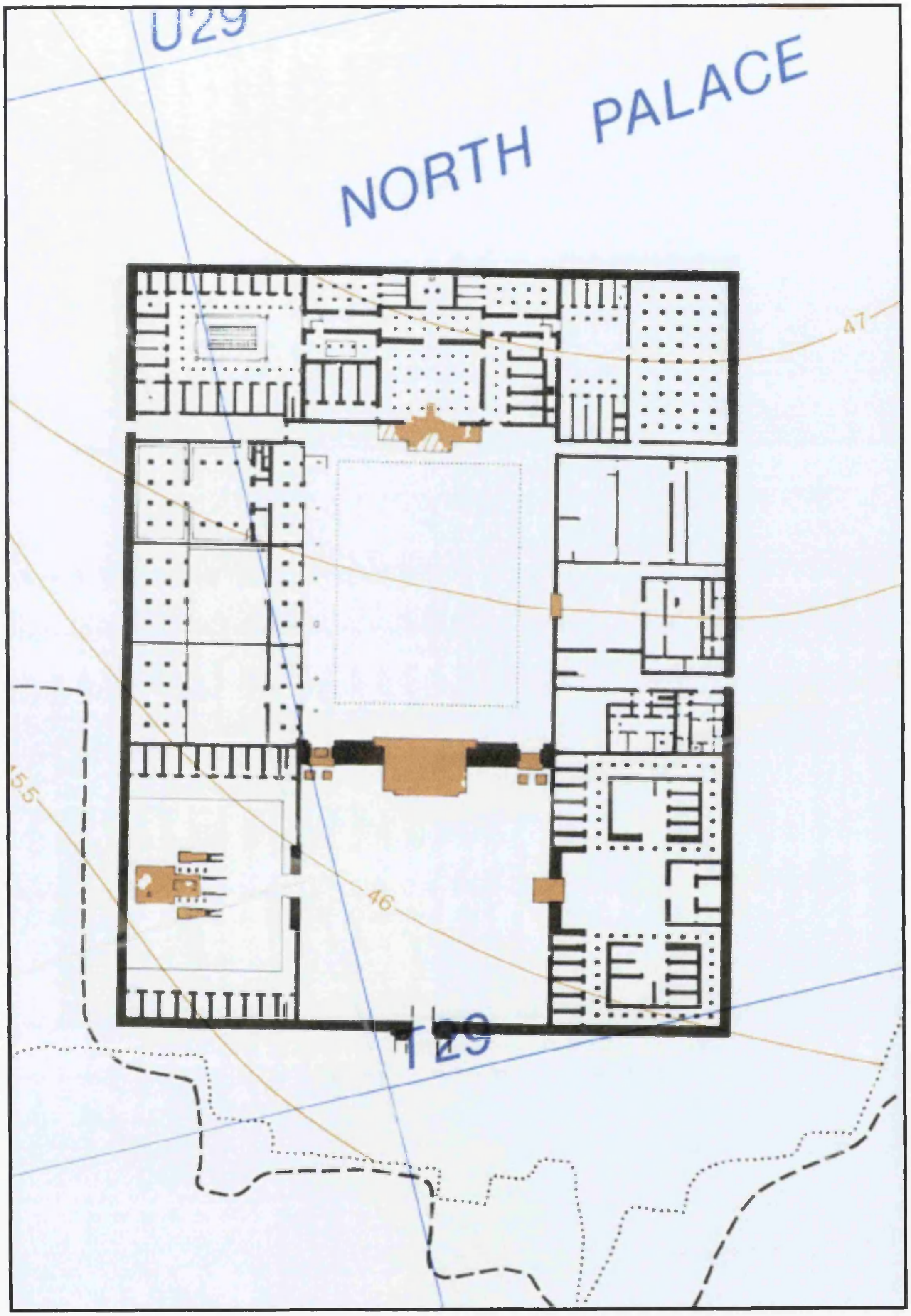



**Figure 5.10: Plan of the Royal North Palace in Amarna.**
After Kemp 2001, Amarna Project, Accessed 21st April 2008, Last Update January 2008. Available from http://www.amarnaproject.com/pages/amarna_the_place/central_city/index.shtml.

**Figure 5.11: The bases of the circular granaries found in the private estates at Amarna.**
After Kemp 1991: 299, Plate 11.

# Chapter 6 Figures: Bronze

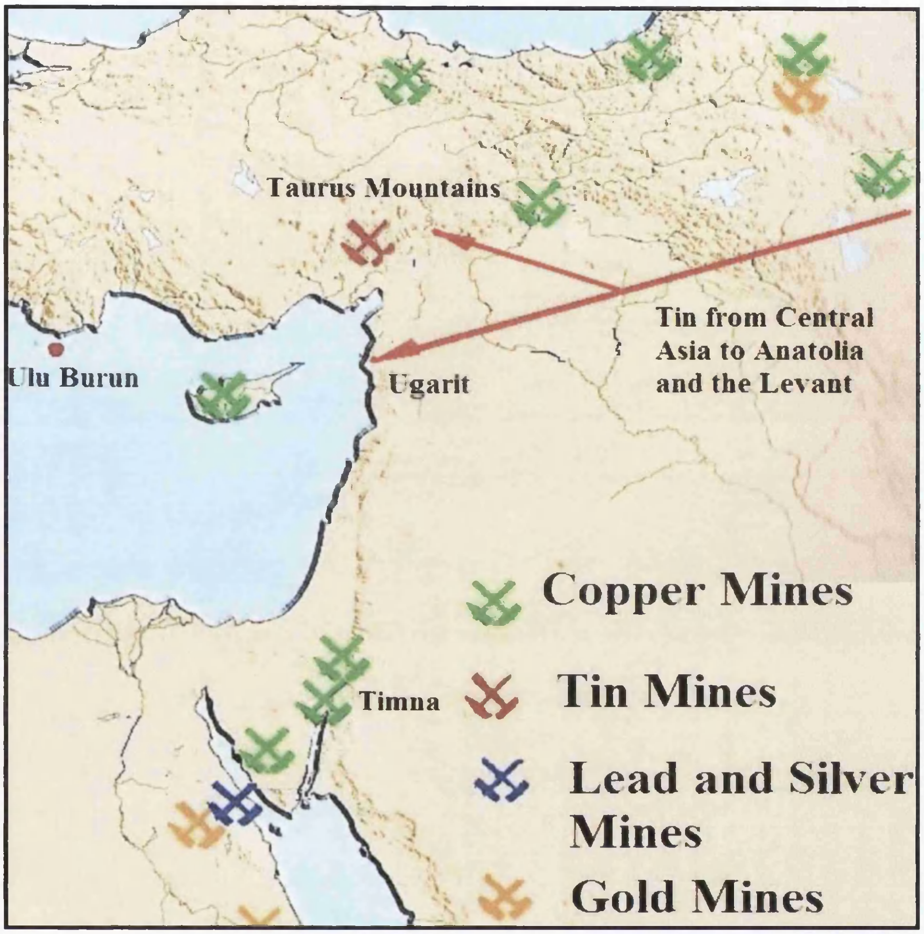



**Figure 6.1: Metals mined in antiquity in the Eastern Mediterranean.**
Adapted from Yalçin et al 2005: 452.

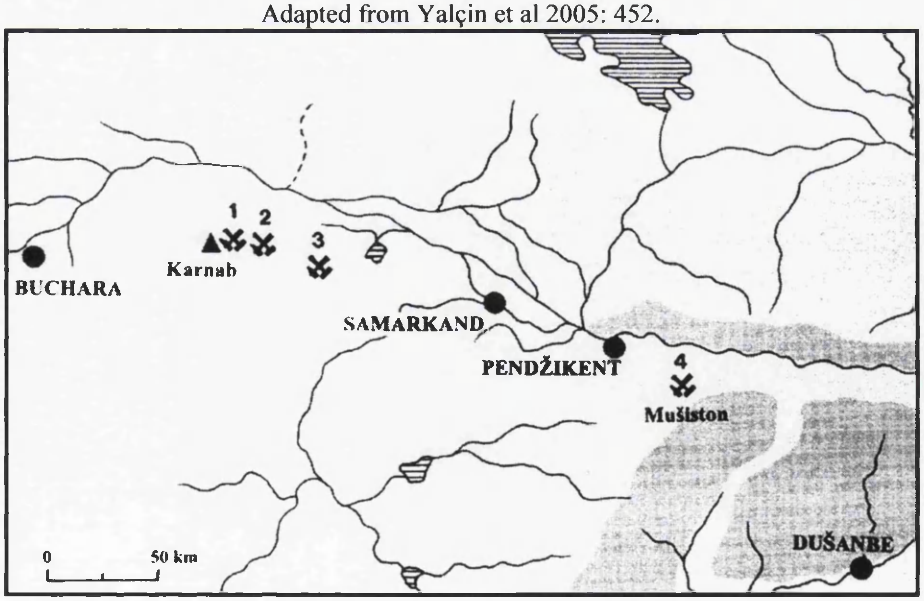
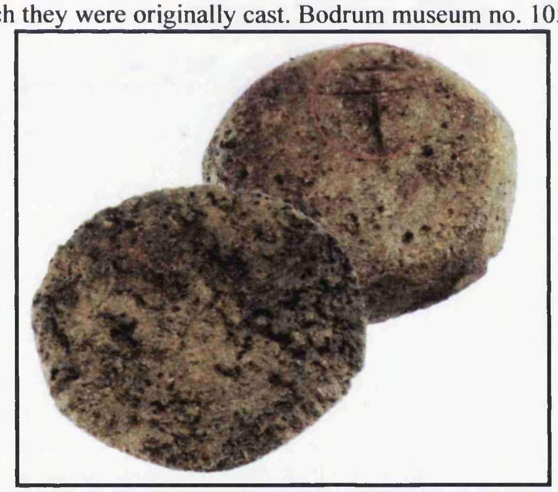



**Figure 6.2: Tin deposits in central Asia.**
After from Cierny 2003: 25, figure 1.

(a) Ulu Burun copper oxhide ingot weighing 23.4 4 kg. Bodrum museum no. 106.5.87, KW 869. (b) Oxide ingot mould found at Ras Ibn Hani (Ugarit).

(c) Ulu Burun copper 'cushion' ingots weighing 10.966 kg, clearly showing the rough side from the mould from which they were originally cast. Bodrum museum no. 105.24.86, KW 869.



(d) Ulu Burun plano copper ingots weighing 6.112 kg. Note the incised markings thought to be Cypro-Minoan administration details. Bodrum museum no. 117.24.86, KW 623.

**Figure 6.3: Oxhide, cushion and plano copper ingots recovered from the Ulu Burun wreck.**
After Yalçin: 2005: 562, 567, 569.

(a) Ulu Burun oxhide tin ingots weighing 22.122 kg and 11.638 kg. Bodrum museum numbers 32.5.90, KW 1932 and 2003.1.7, KW644.

(b) Rectangular slab tin ingots and plano tin ingots weighing 10.048 kg and 4.402 kg . Bodrum museum numbers. 2003.1.10(A), KW518, and 45.24.86, KW 401.

**Figure 6.4: Oxhide, rectangular, and plano shaped tin ingots from the Ulu Burun wreck.**
After Yalçin: 2005: 572,574.

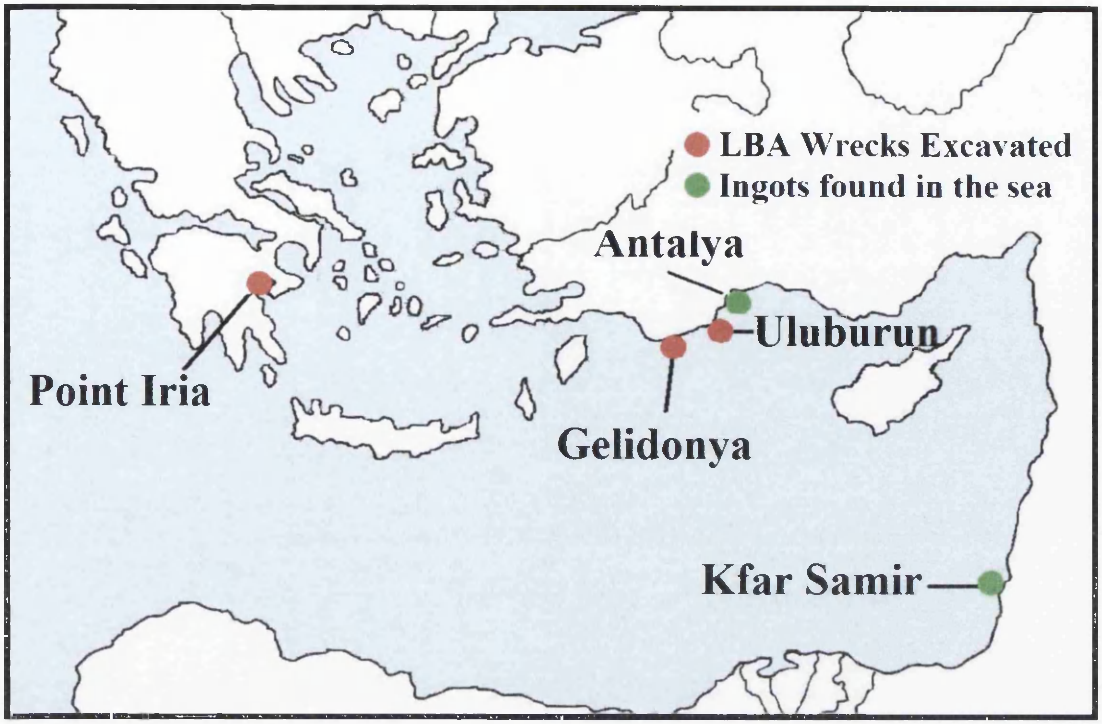



**Figure 6.5: Sites of the LBA wrecks.**

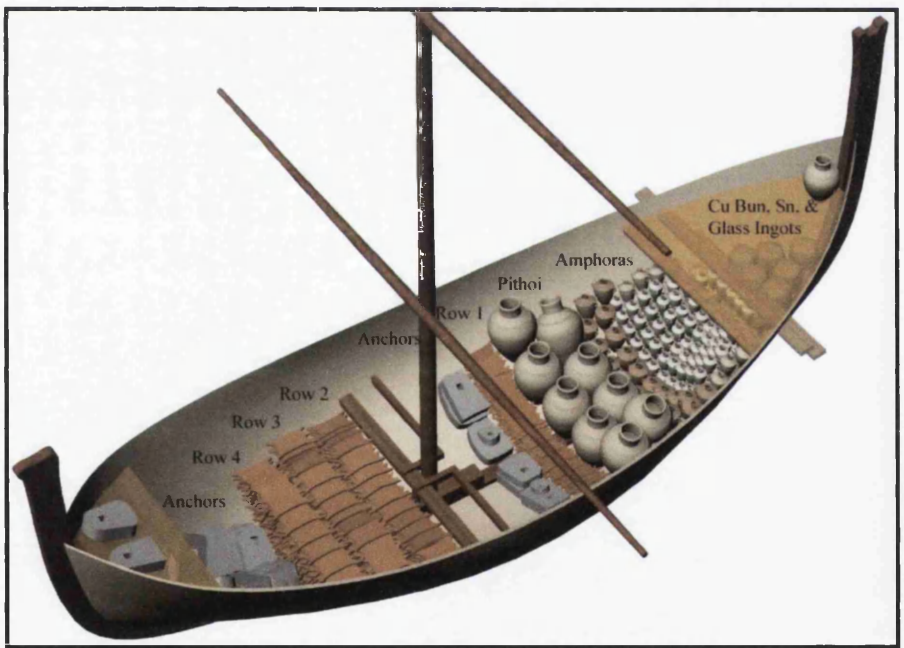



**Figure 6.6: Reconstruction of the Ulu Burun wreck and the distribution of cargo.**
Adapted from Lin 2003: 205, Figure 7.1.

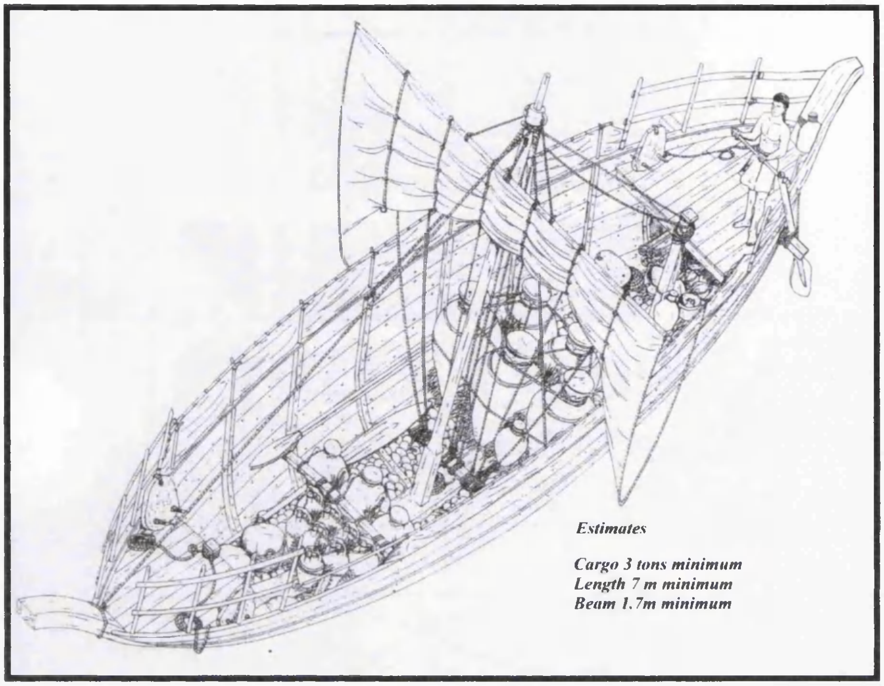



**Figure 6.7: Reconstruction of the Point Iria wreck.**
Adapted from Vichos 1999: 98, figure 16 based on a drawing by Y. Nakas, 1998.

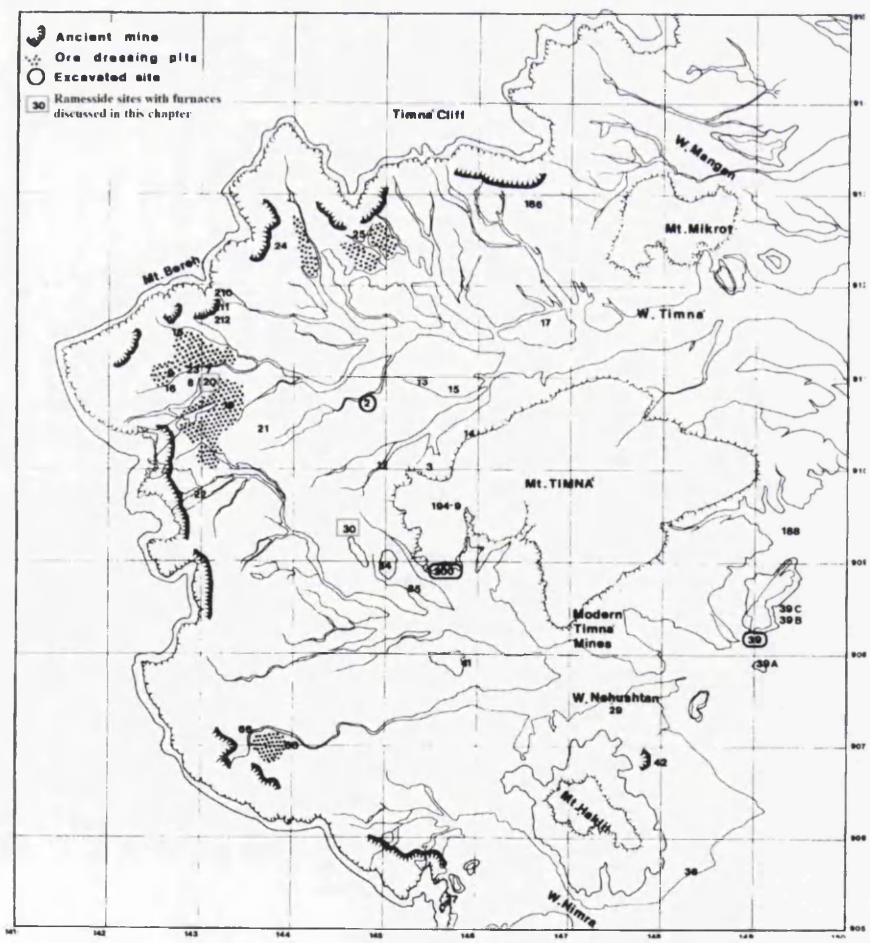



**Figure 6.8: Map of Timna showing the positions of the two LBA Ramesside smelting sites.**
Adapted from Rothenberg 1972: 26, Figure 6.

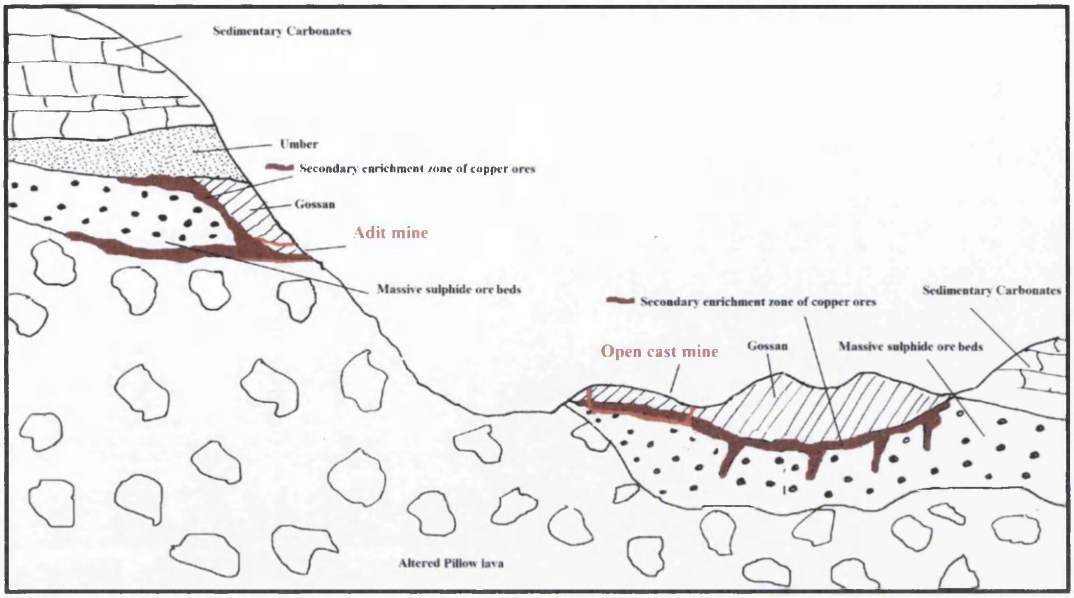



**Figure 6.9: Typical locations of adit and open-cast mines on the pillow lavas of the Troodos Mountains.**

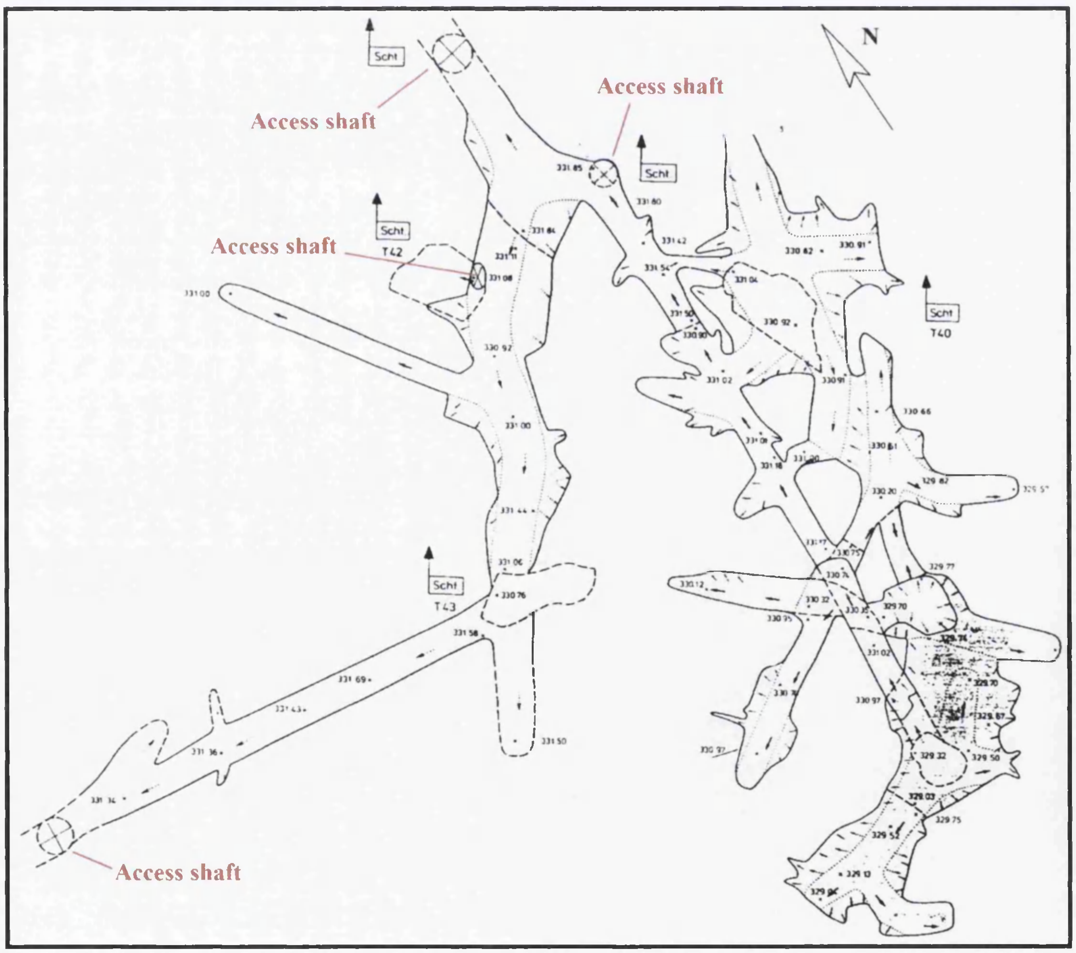



**Figure 6.10: Typical warren of galleries, interconnected tunnels, and gallery access shafts at Timna.**

Adapted from Craddock 1995: 70, Figure 2.32.

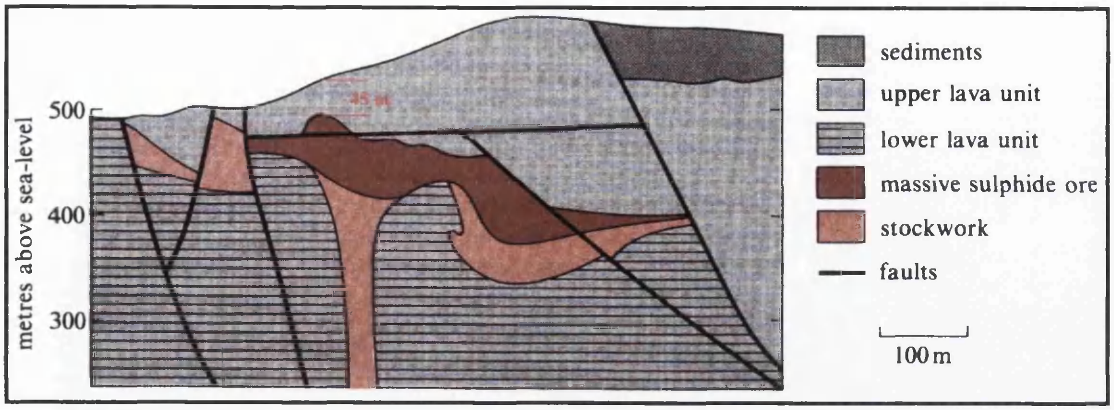



**Figure 6.11: Geological and weathering processes of Cypriot copper sulphide ores.**
Adapted from Open University 2006: 11, Figure 3.

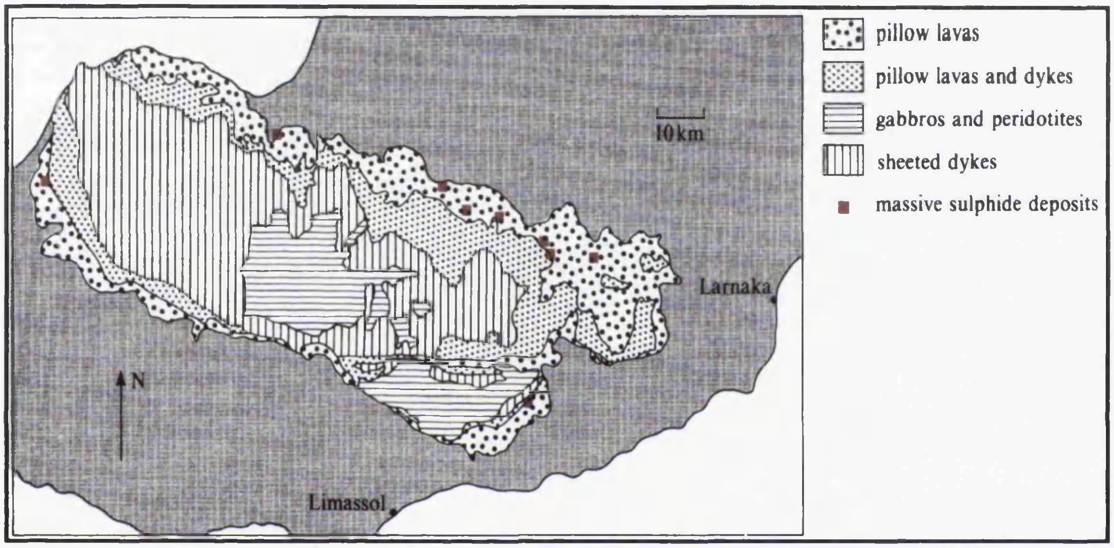



**Figure 6.12: Geological map of the Troodos Mountains, Cyprus**
Adapted from Open University 2006: 47, Figure 37a

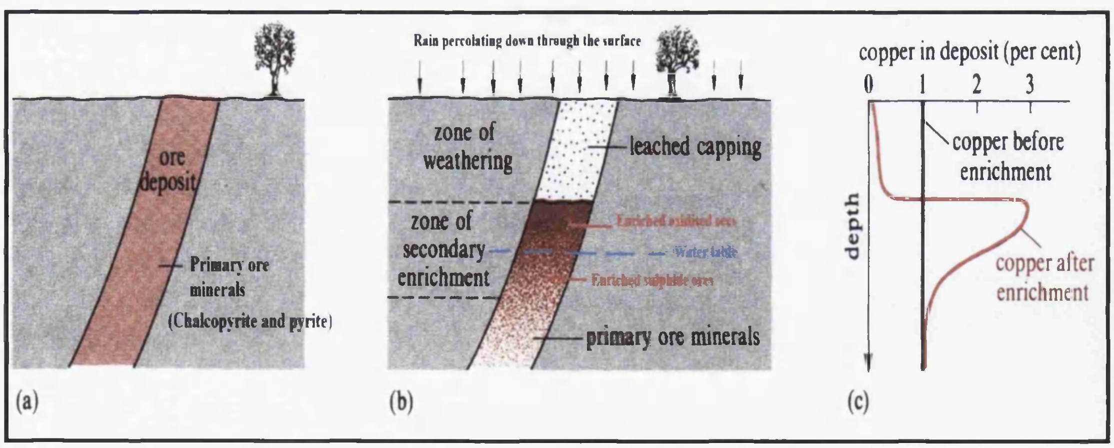



**Figure 6.13: Geological and weathering processes of Cypriot copper sulphide ores.**
Adapted from Open University 2006: 11, Figure 3.

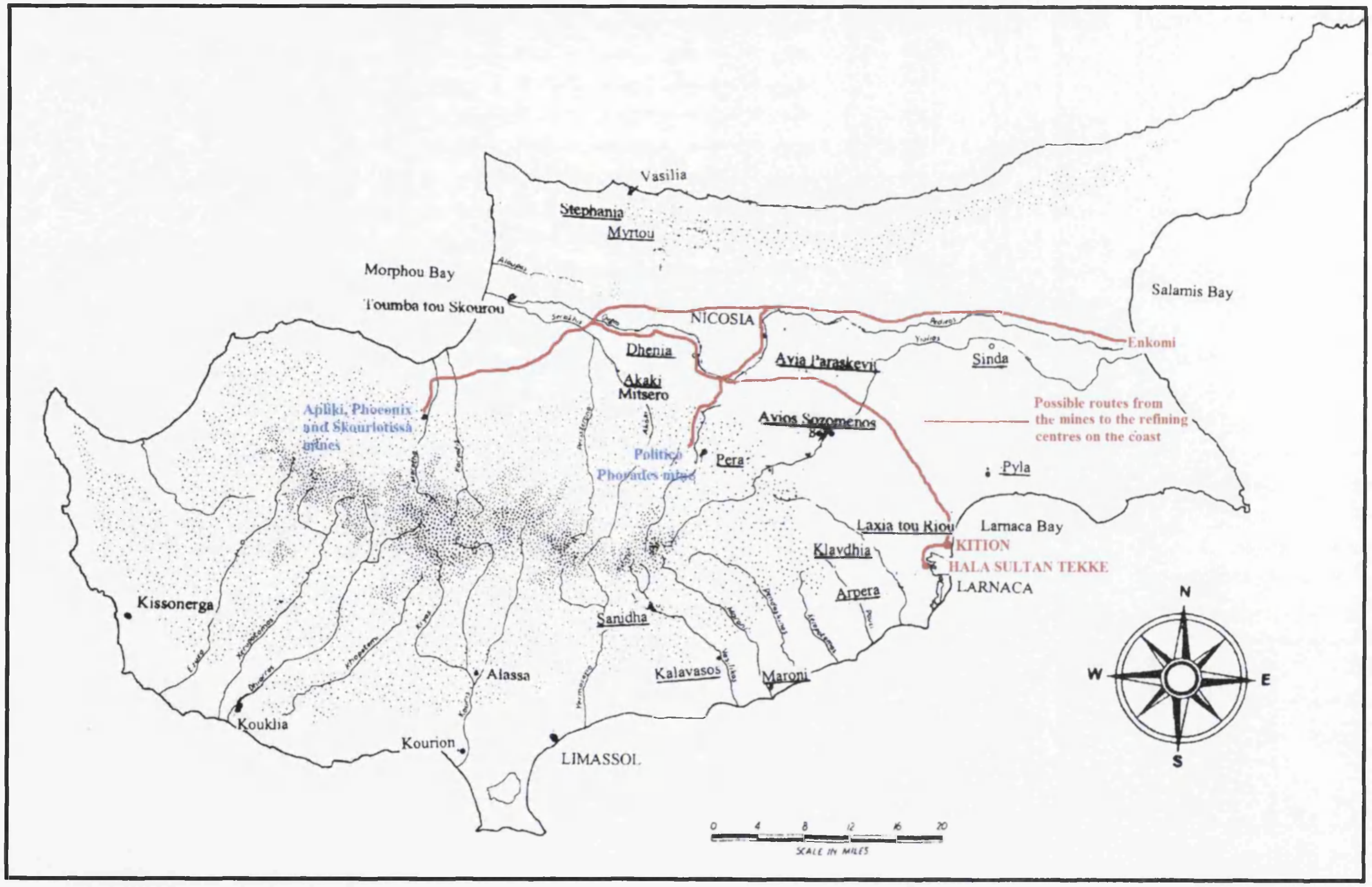



**Figure 6.14: Locations of LBA mines and possible routes used in the LBA to transport black copper from smelting centres at the mines to refining centres on the coast.**
Adapted from Hatcher 2007: 205, Map 3.

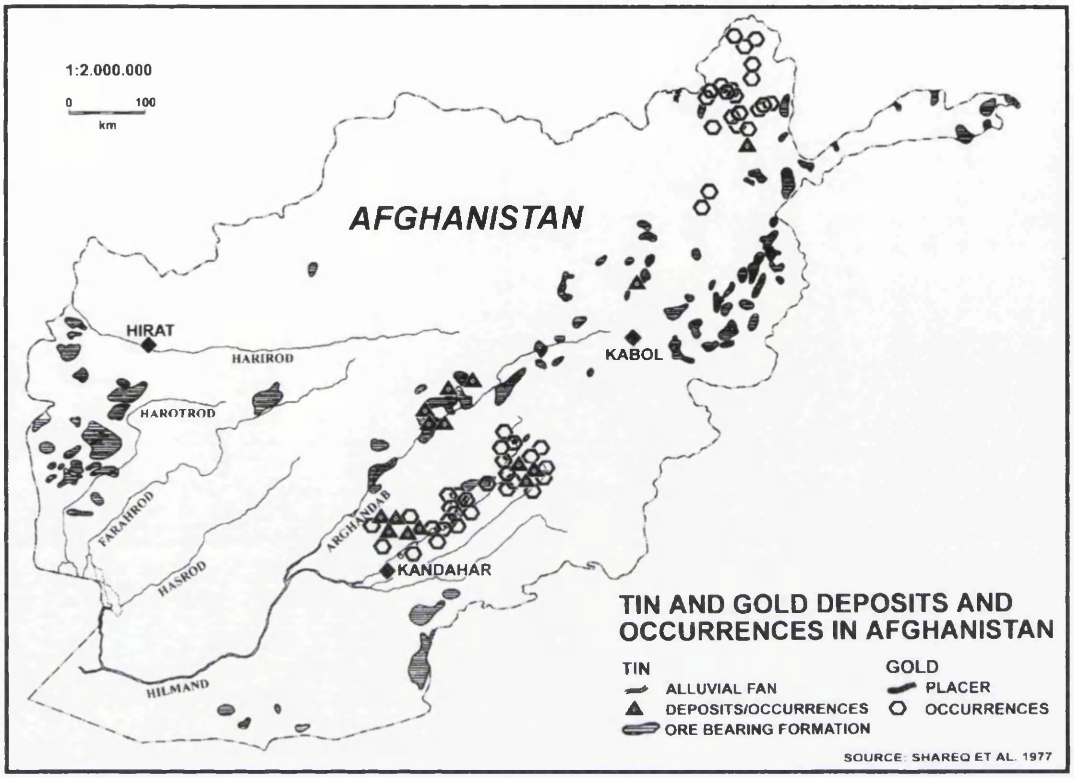
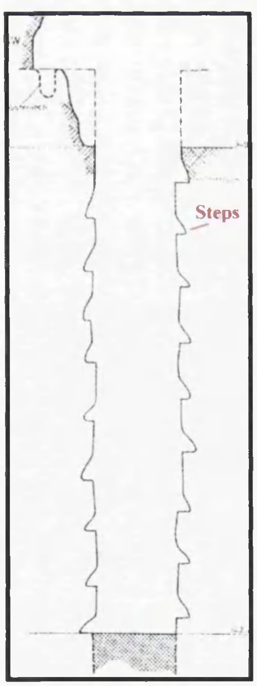



**Figure 6.15: Map of tin and gold deposits and occurrences in Afghanistan.**
After Pigott 1999: 117, Figure 9.



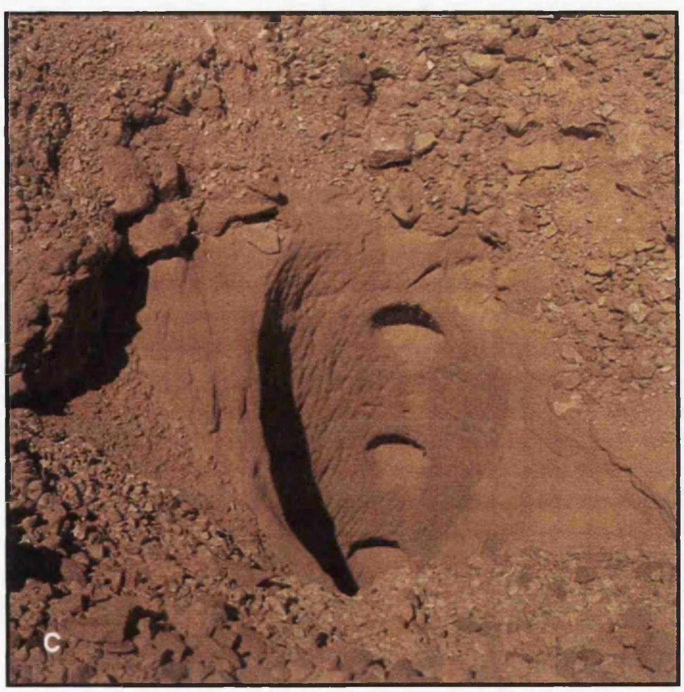




**Figure 6.16: Access shaft to the Timna mining galleries. The photograph shows the cut steps.**
Drawing adapted from Conrad et al 1980: 160, abb. 188. Photograph after Bachmann 1980: 15.

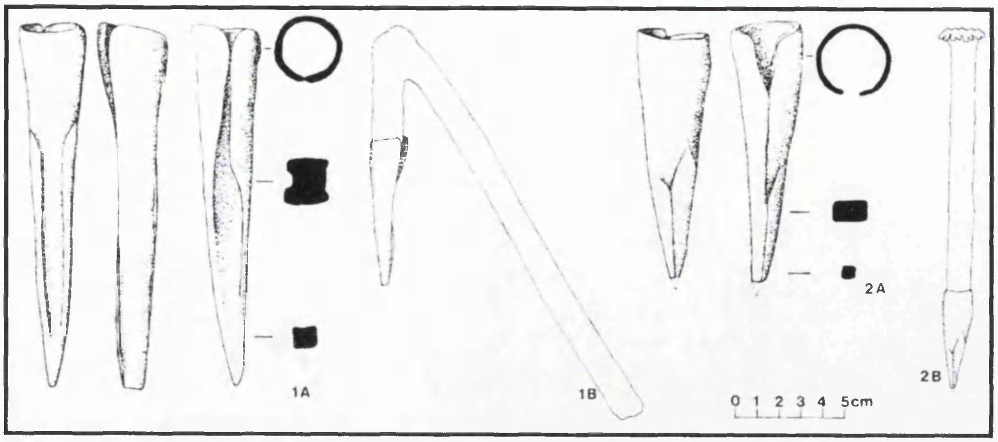



**Figure 6.17: Bronze sockets fitted to wooden handles used to cut shafts and tunnels.**
After Conrad et al 1980a: 84.

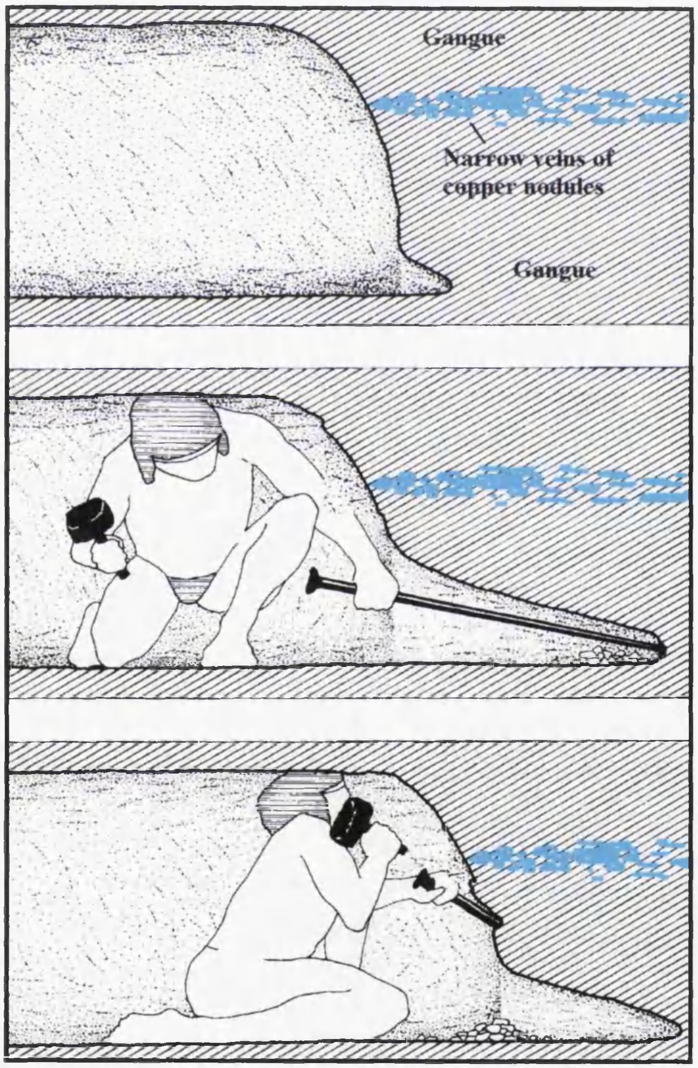



**Figure 6.18: Method of undercutting used to excavate galleries at Timna.**
Adapted from Conrad 1980: 84, Figure 70.

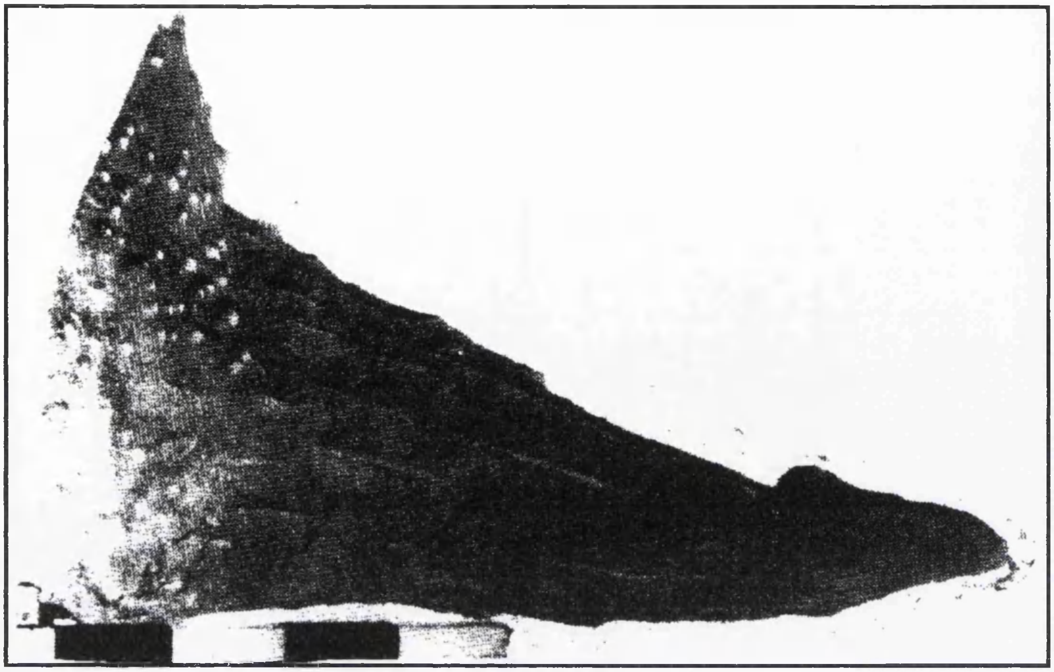


**Figure 6.19: Section of an undercut gallery at Timna.**
After Conrad 1980: 84, Figure 70.

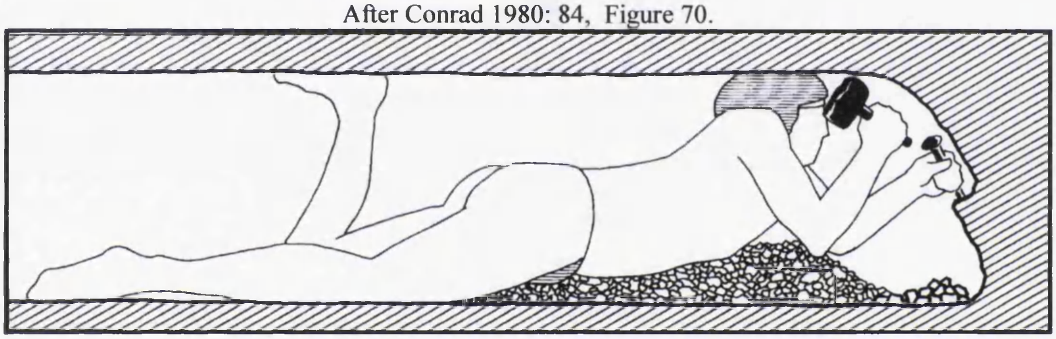


**Figure 6.20: Method of excavating small link tunnels connecting galleries.**
After Conrad 1980: 84, Figure 73.

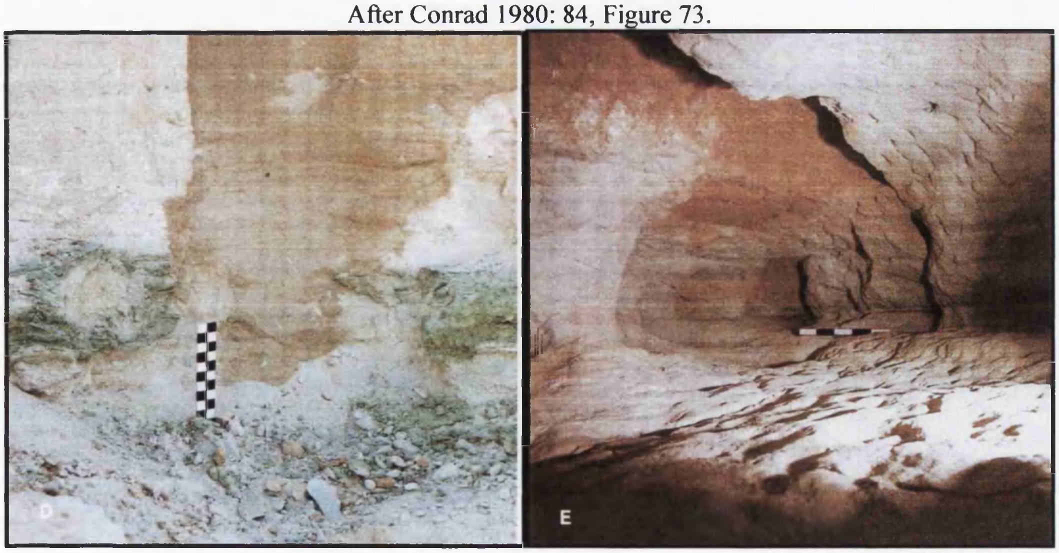



**Figure 6.21: Veins of copper-rich nodules in the Timna mines.**
After Bachmann 1980: 15, Figures D and E.

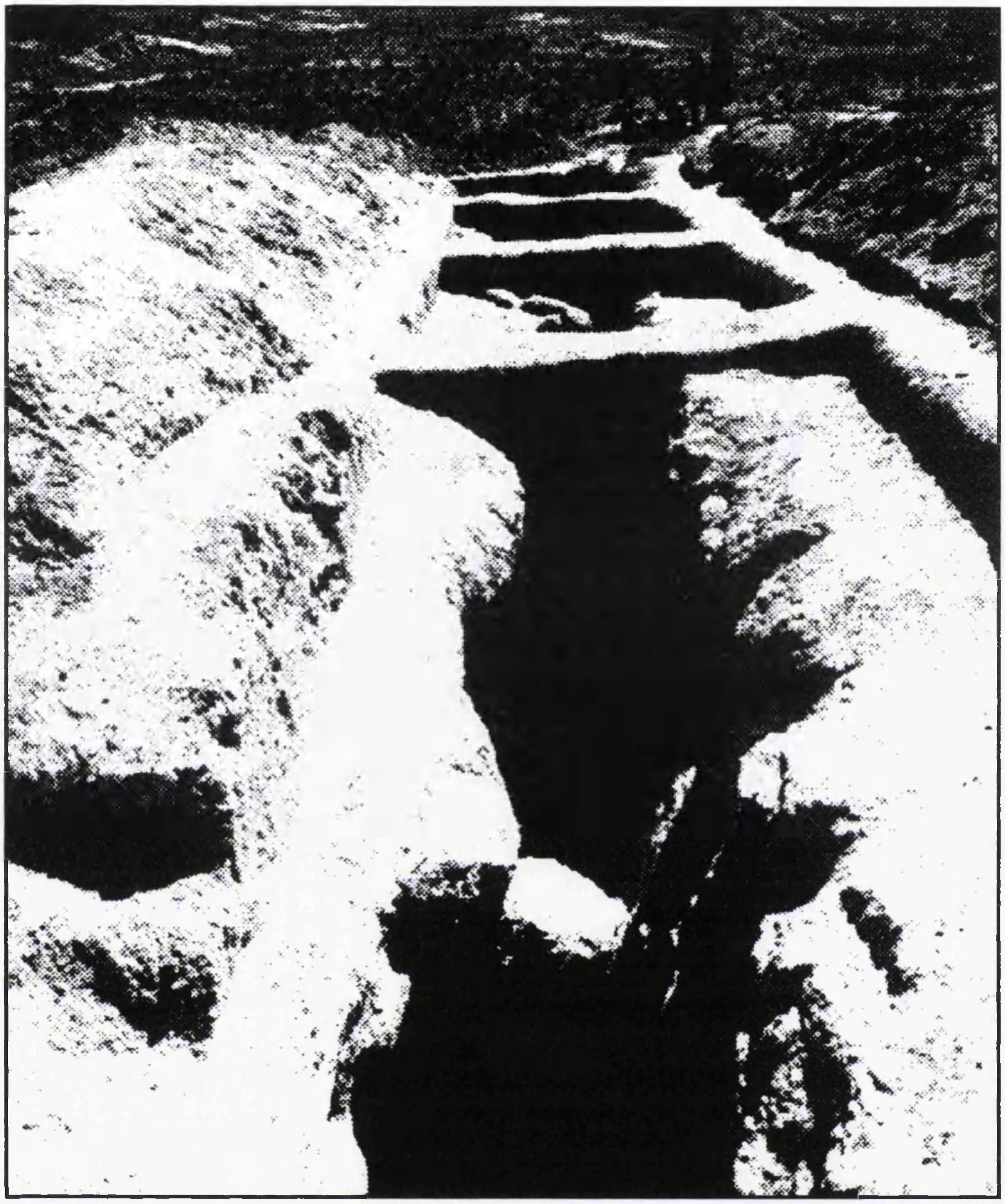


**Figure 6.22: Trench mine at Karnab mine 5 with rock support bridges, in Uzbekistan.**
After Cierny and Weisgerber 2003 26, Figure 6.

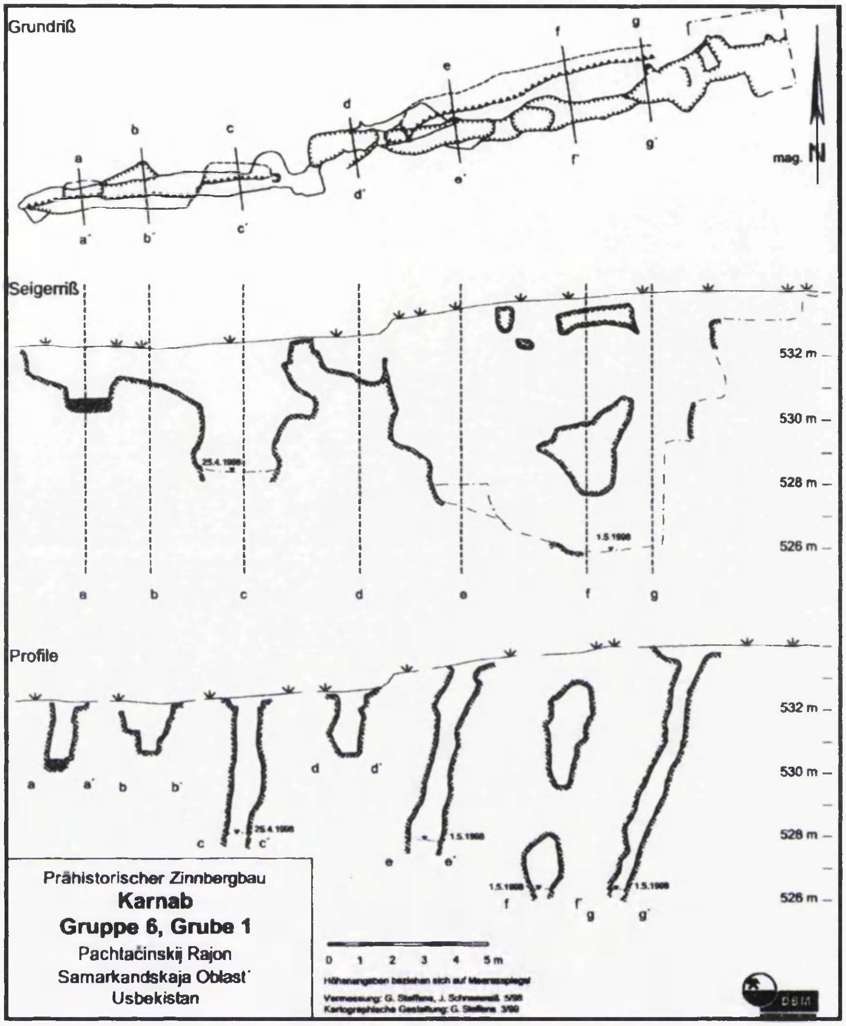



**Figure 6.23: Plan, cross-section, and side elevation of the trench mines at Karnab, Uzbekistan.**
After Cierny 2003: 31, Figure 12.

**Figure 6.24: Firesetting experiment in progress at Cwmystwyth, central Wales.**
After Craddock 1995: 35, Figure 2.5.

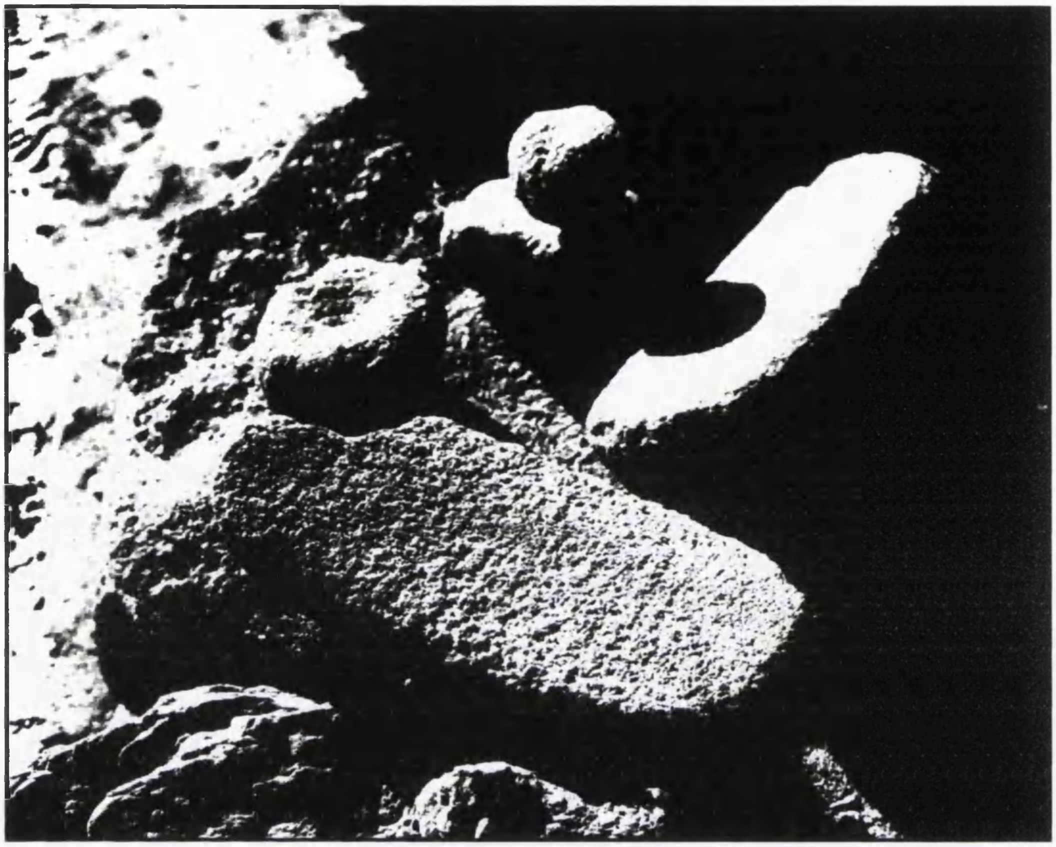


**Figure 6.25: Tools used in the beneficiation process.**
After Conrad 1980: 177, Abb. 201.

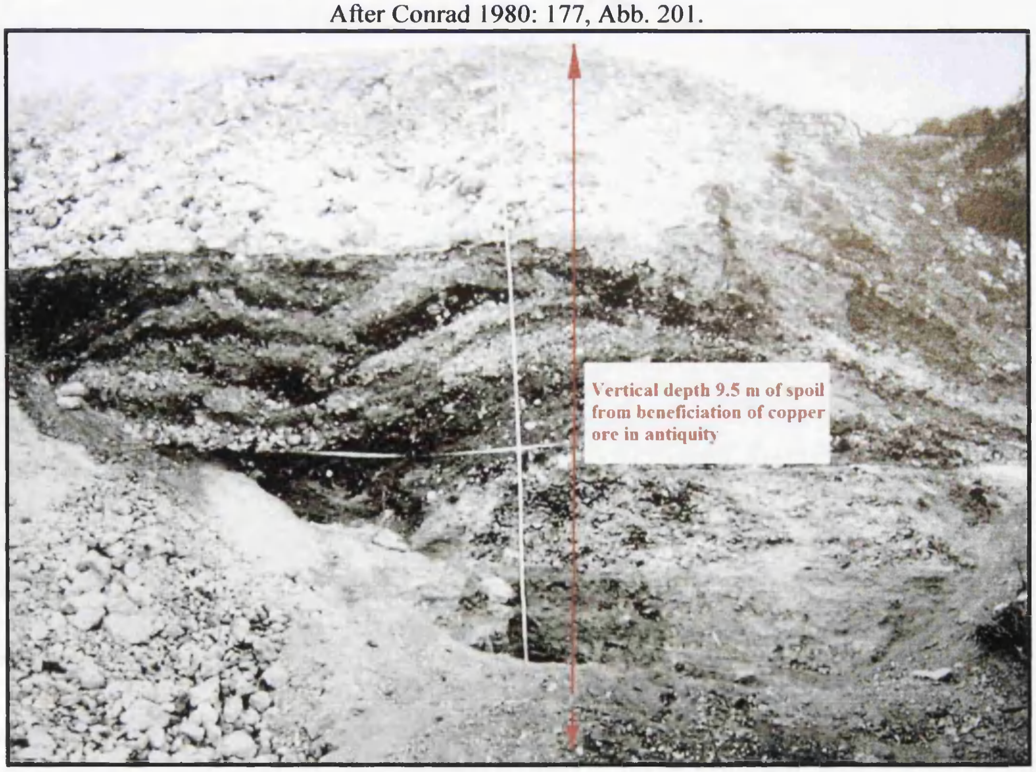



**Figure 6.26: Ancient spoil heaps from the beneficiation of copper ore in antiquity.**
Adapted Given 2003: 65, Figure 4.3.

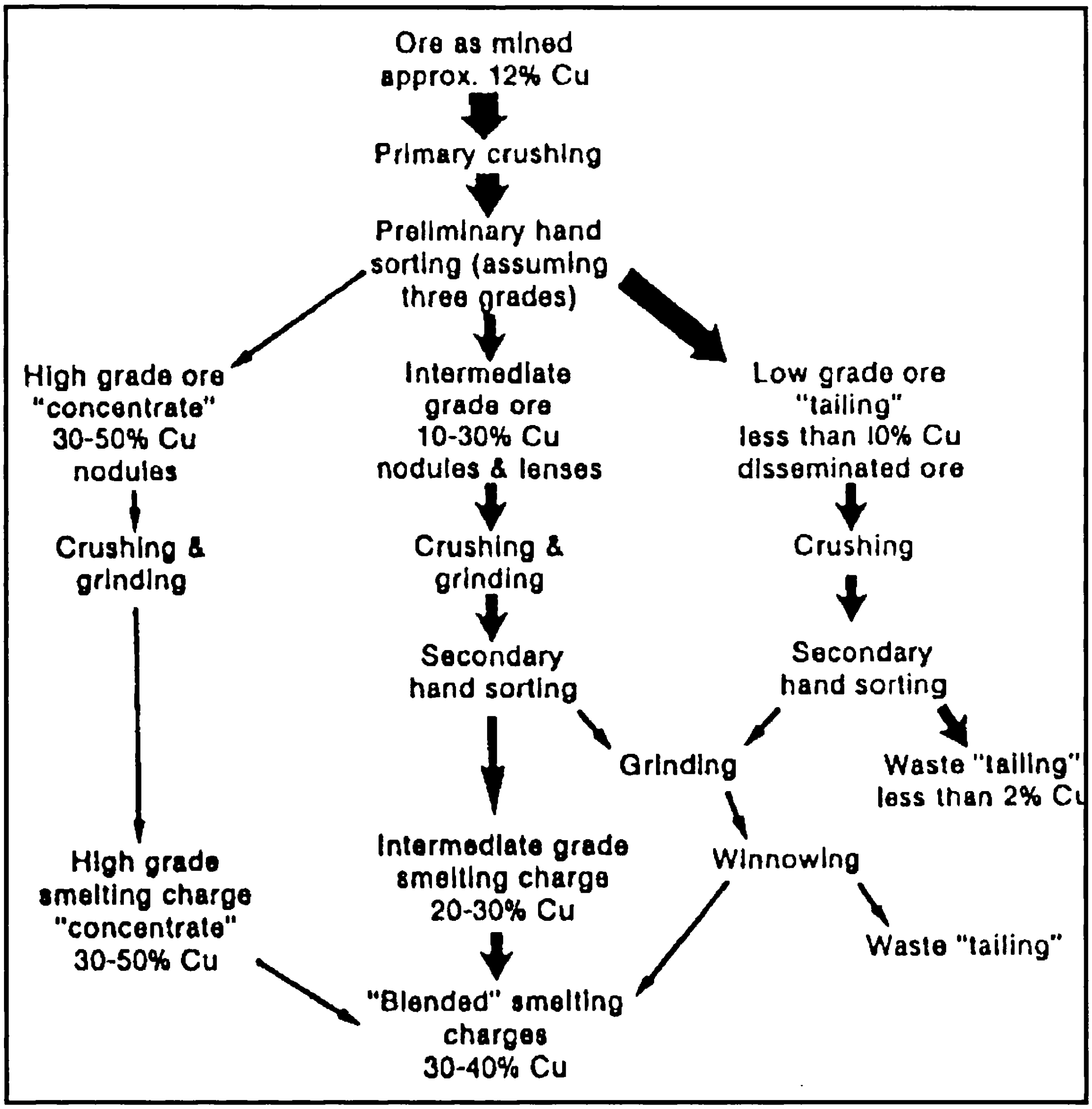



**Figure 6.27: Flow chart of the possible beneficiation activities for copper ore in the LBA.**
After Merkel 1985: 165, Figure 1.

**Figure 6.28: Field trials of a reconstructed furnace in operation based on the remains of shaft furnaces at sites 2 and 39 at Timna.**
After Merkel 1983a: 176, Plate 2.

**Figure 6.29: Excavated shaft furnace IV, from site 2 at Timna.**
After Rothenberg 1972: 60, Plate VII.

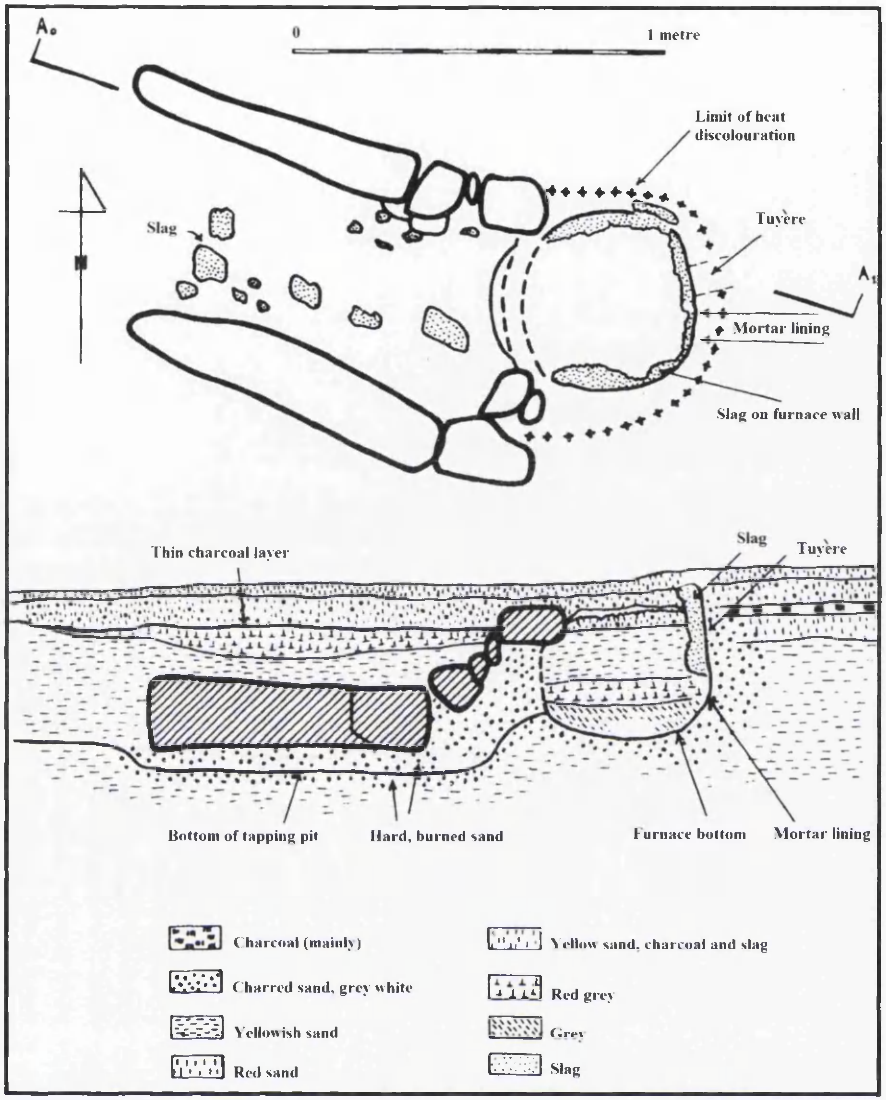



**Figure 6.30: Plan and section of Ramesside furnace IV, site 2 at Timna.**
After Rothenberg 1971: Figure 3.

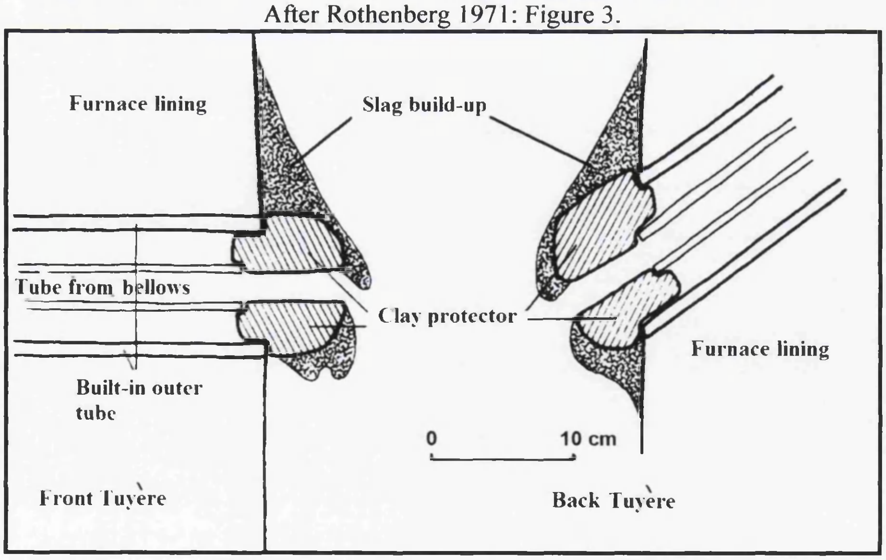



**Figure 6.31: Details of tuyères at back and front of furnace IV , site 2 at Timna.**
After Rothenberg 1972: 76, Figure 20.

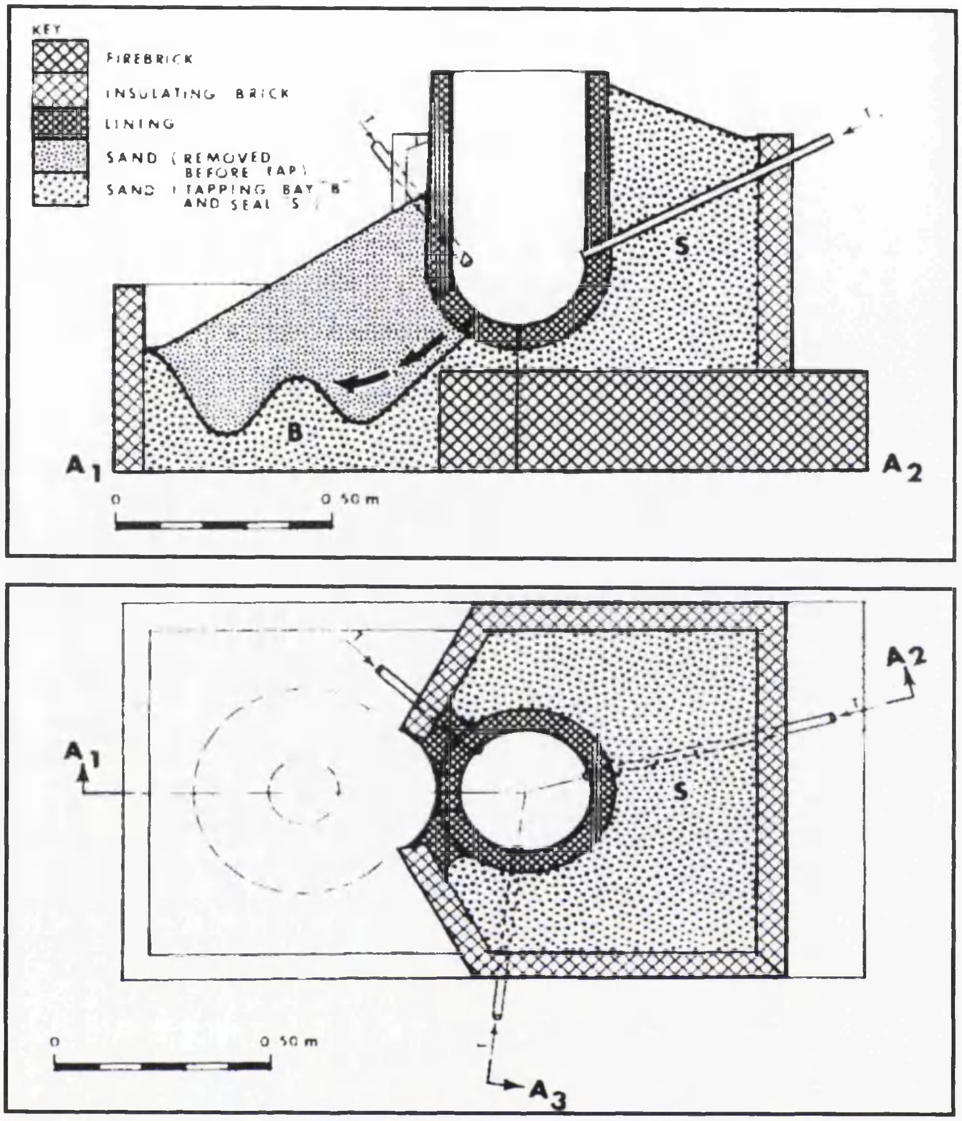



**Figure 6.32: Merkel's laboratory furnace based on the design excavated in Timna site 30, used for his smelting and refining experiments.**
After Merkel 1990: 85, Figure 111.

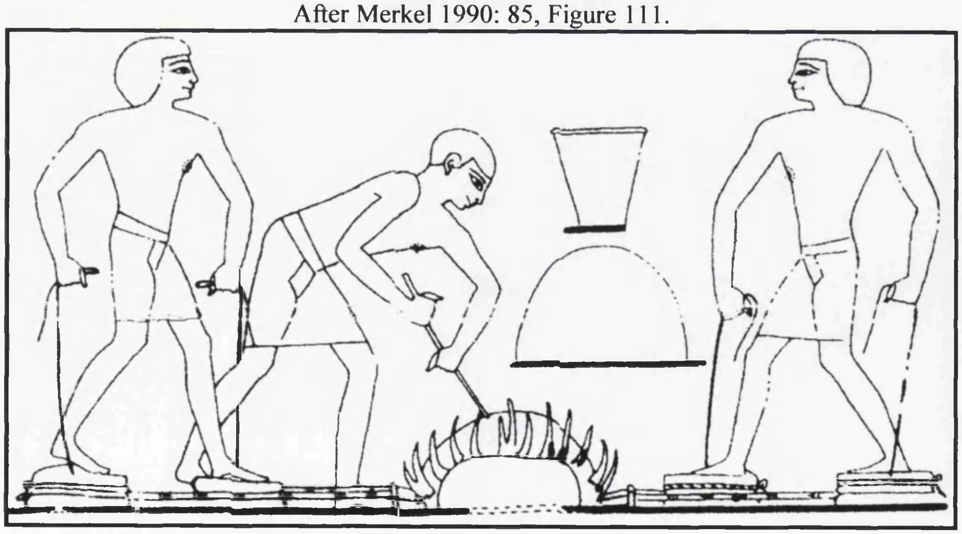


**Figure 6.33: Refining or alloying scene from Rekhmire Tomb in Thebes.**
After Davies 1973: Plate LII.

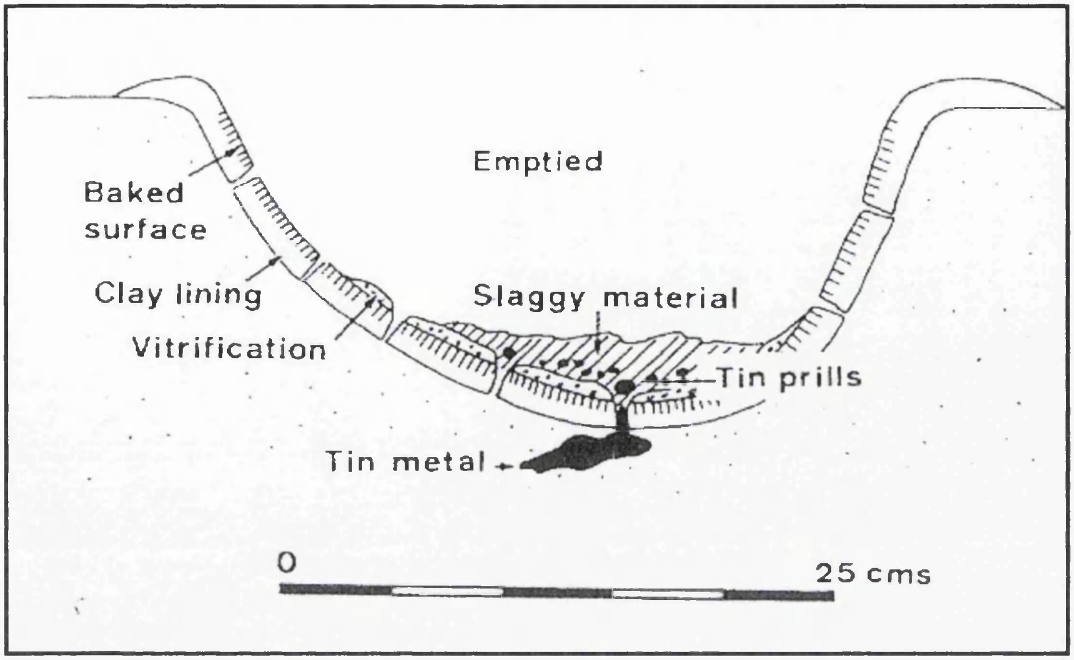



**Figure 6.34: Clay-lined crucible furnace used by Timberlake to smelt cassiterite ore.**
After Timberlake 1994: Figure 6.

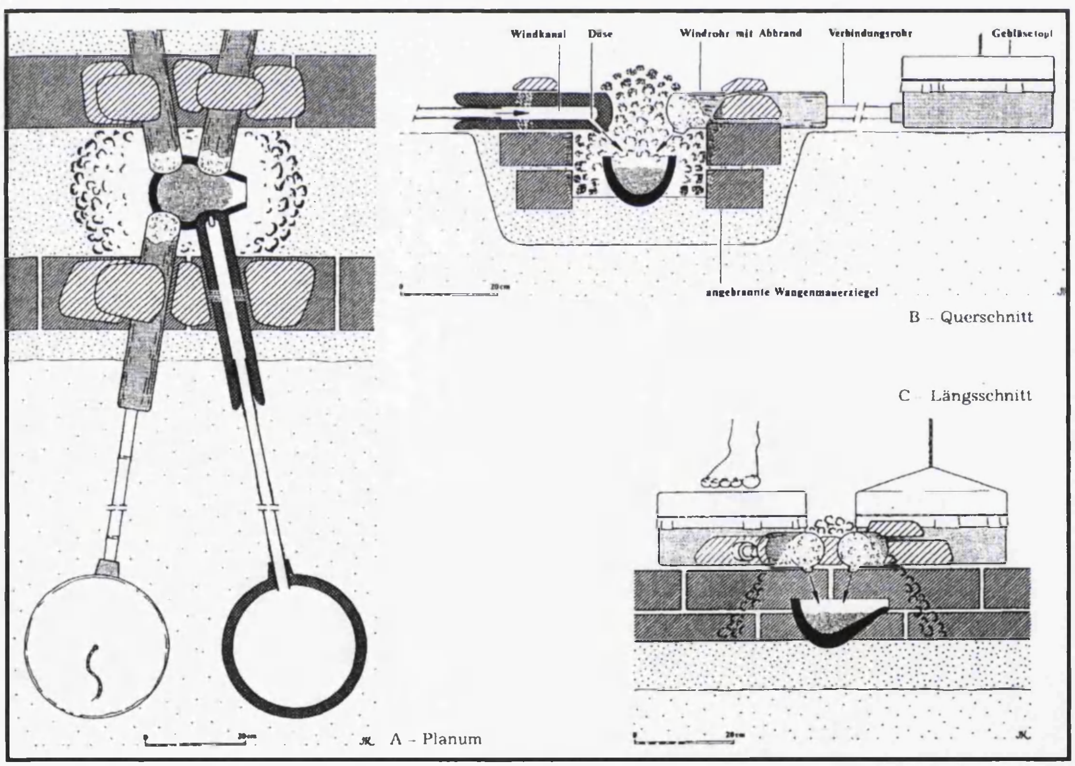



**Figure 6.35: Cruicible arrangement with bellows used at Piramesses to refine copper and alloy copper and tin to make bronze.**
After Pusch 1989b: 153, Figure 1.

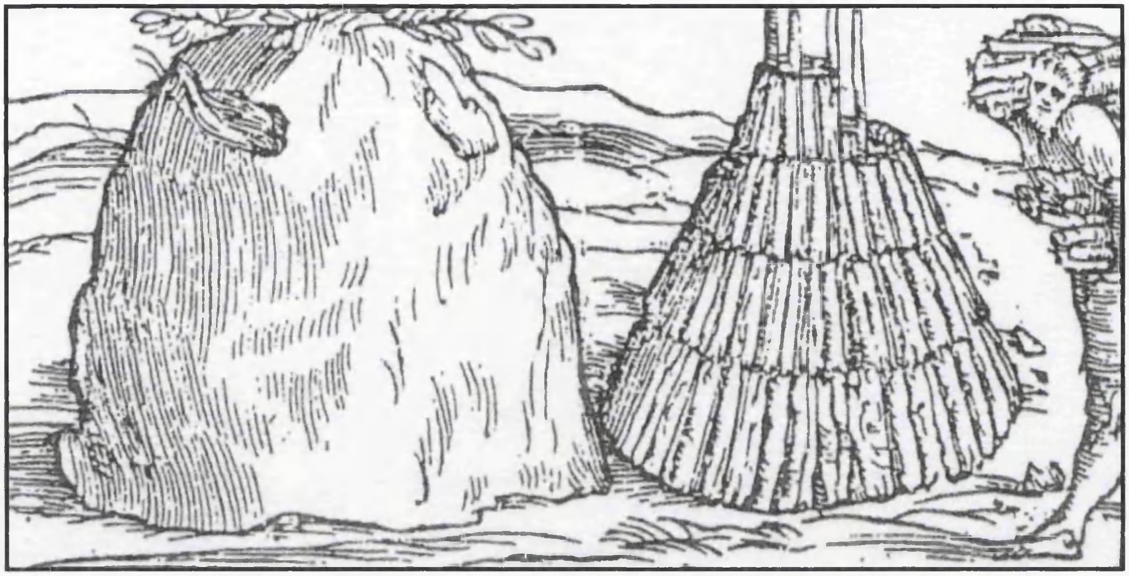


**Figure 6.36: Medieval engraving in *Pirotechnia* by Biringuccio, showing design and operation of a charcoal earth clamp kiln.**
After Pleiner 2000: 120, Figure 29.

**Figure 6.37: Medieval engraving in *Pirotechnia* by Biringuccio, showing design and operation of a charcoal pit kiln.**
After Pleiner 2000: 120, Figure 29.

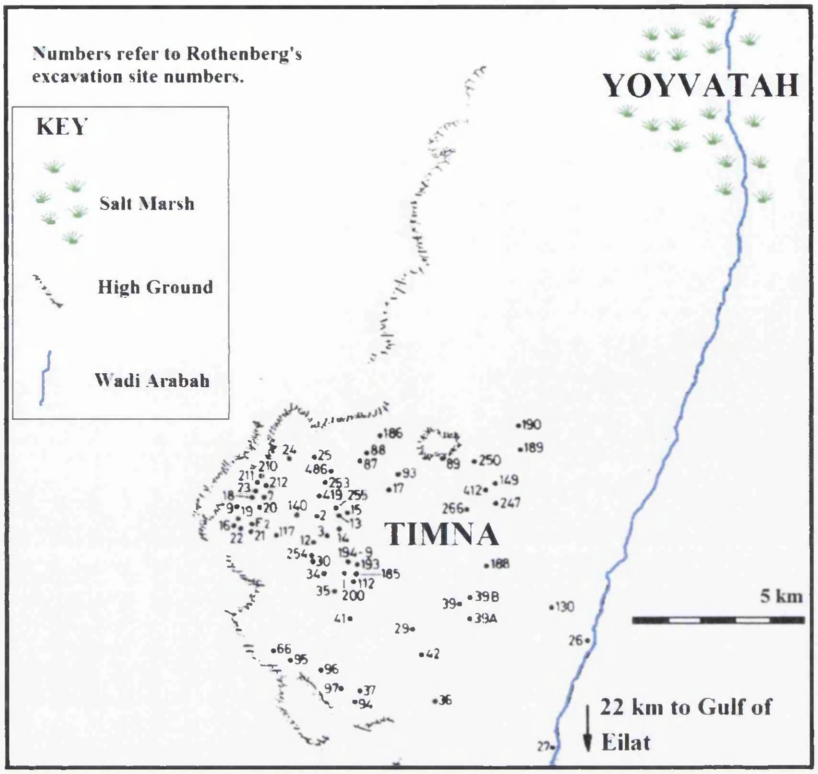



**Figure 6.38: Relationship of Yohvatah and the Wadi Arabah as the source of acacia trees for charcoal production for Timna.**
Adapted from Rothenberg 1988: Illustration 4.

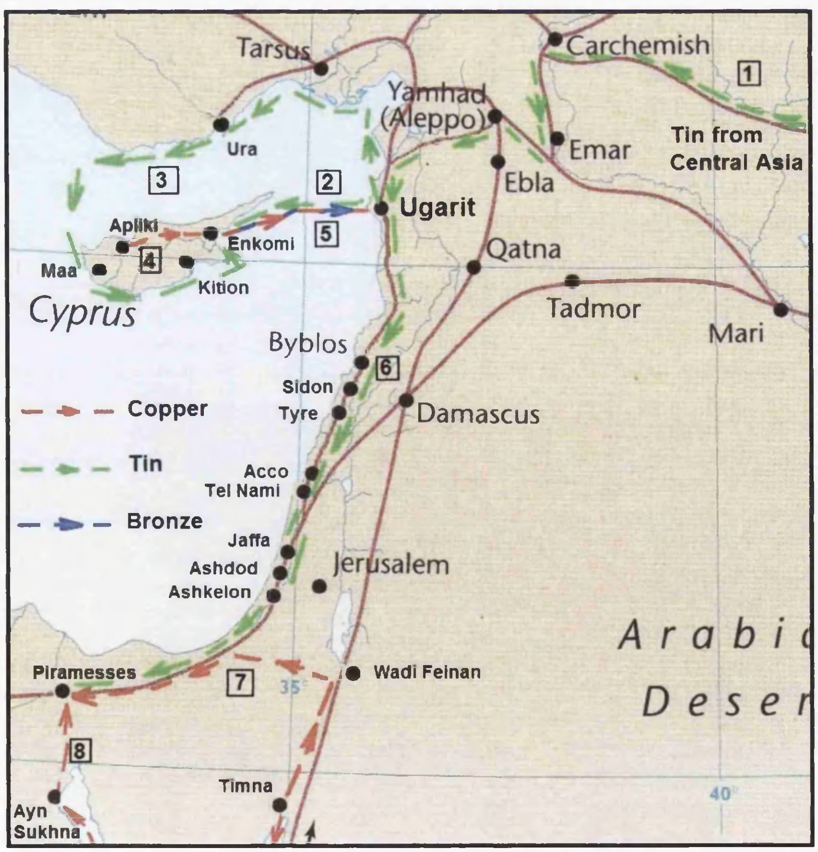



**Figure 6.39: Routes analysed in BRONZECALC for the movement of tin and copper.**

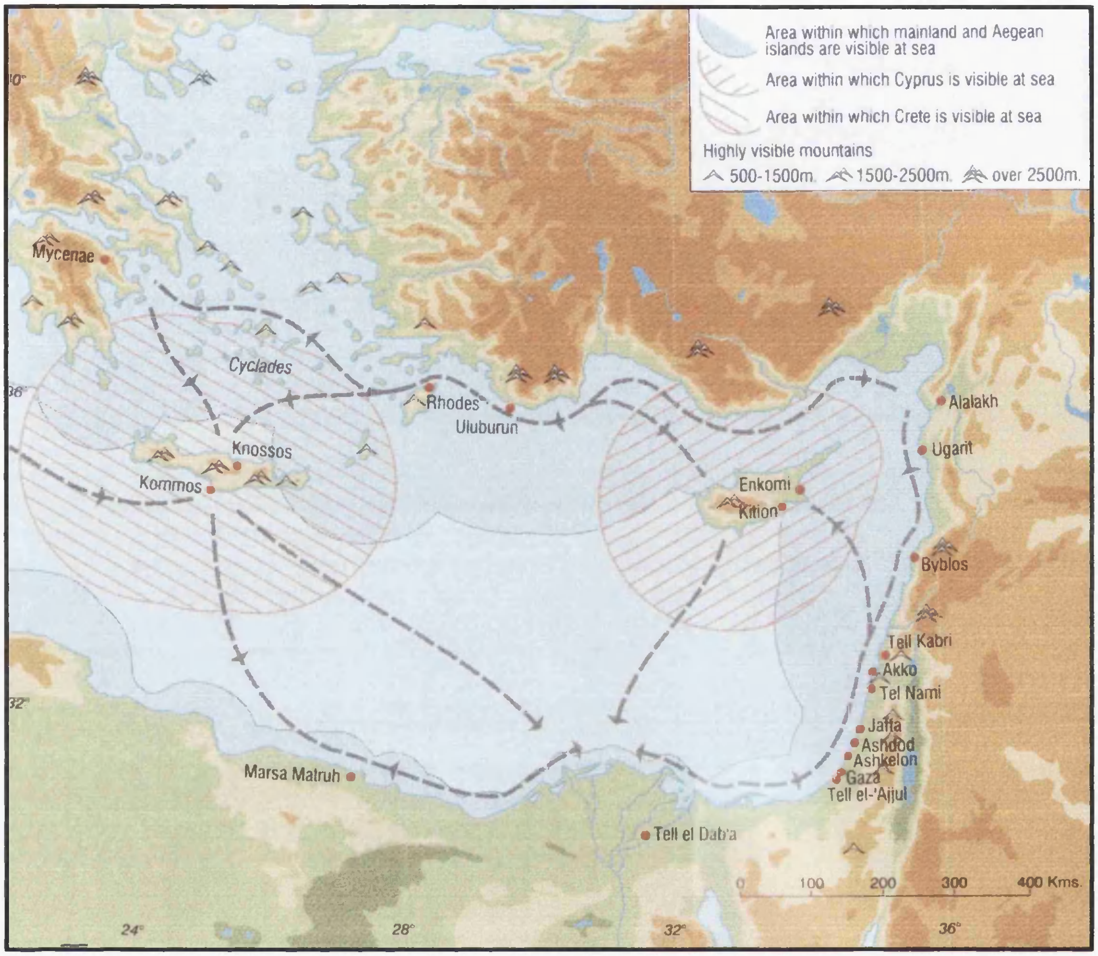



**Figure 6.40: Possible sea trade routes illustrating that for the majority of the journeys the boat was in sight of land that assisted navigation.**
Adapted from Hulin 2006: Map 1.5.

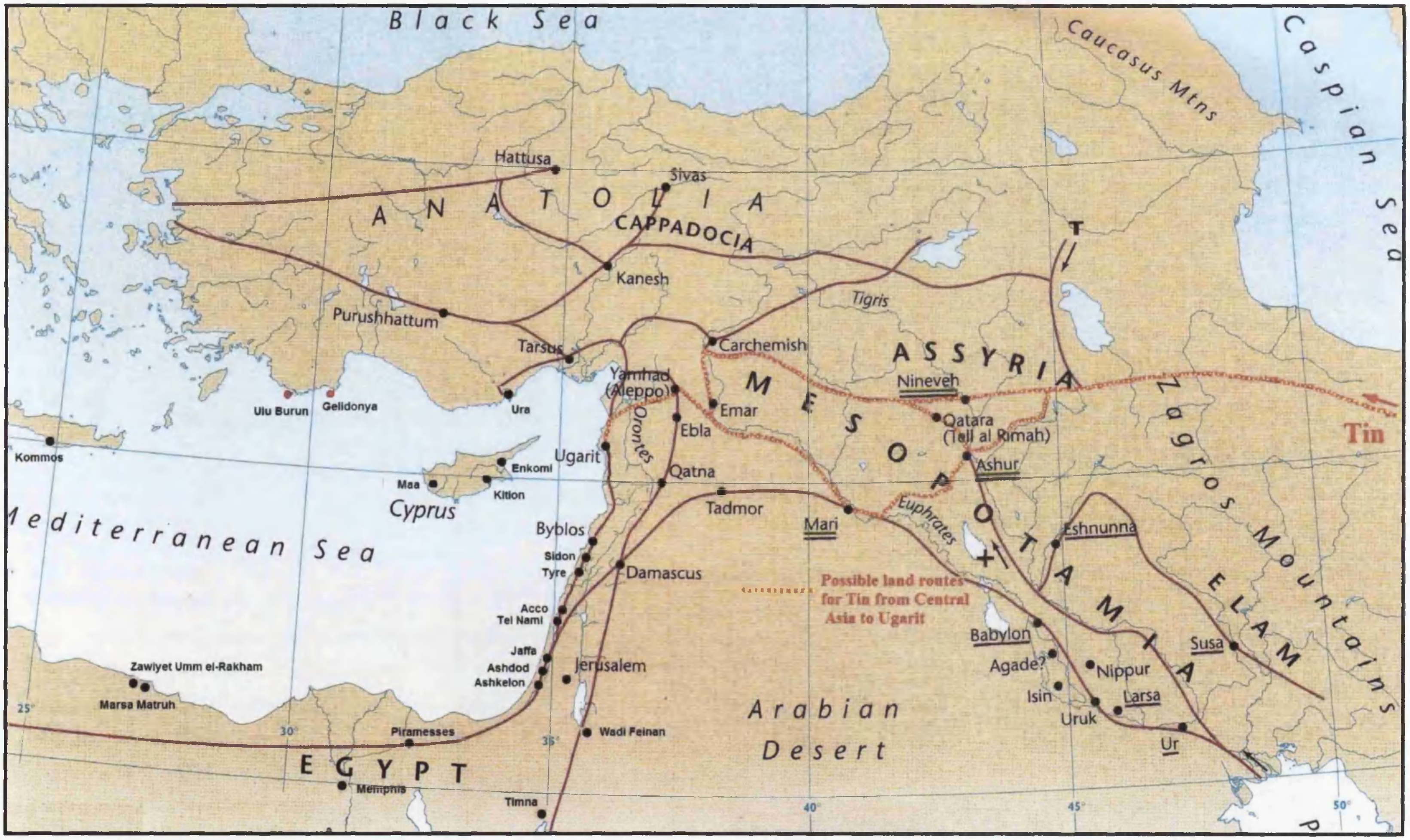



**Figure 6.41: Possible routes for tin from central Asia to Ugarit.**
Adapted from Yalçin: 2005: 580-581 and Revised Times History Atlas 2006: 18.

**Figure 6.42: Ugarit's natural harbour, Mahadu.**
After Yon 2006: 10, Figure 5a.

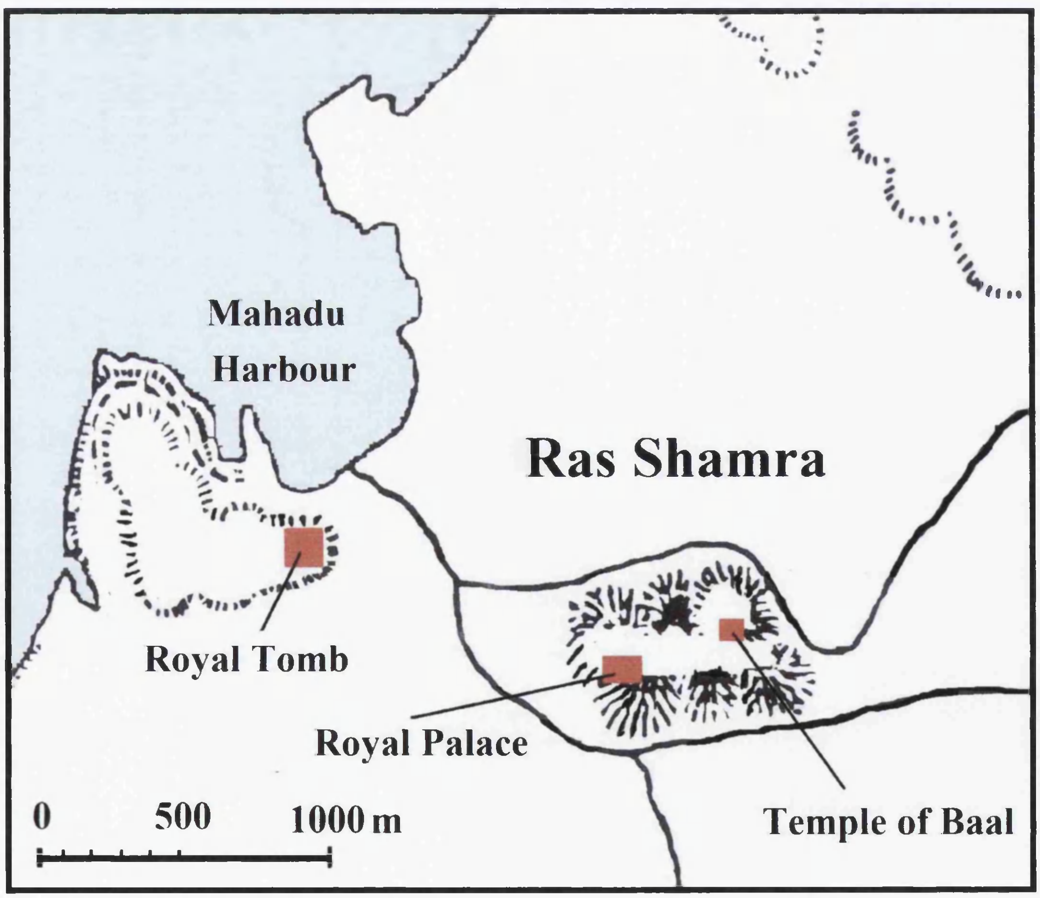



**Figure 6.43: Relationship of the port of Mahadu to Ugarit's capital city Ras Shamra.**
Adapted from Yon 2006: 10, Figure 5

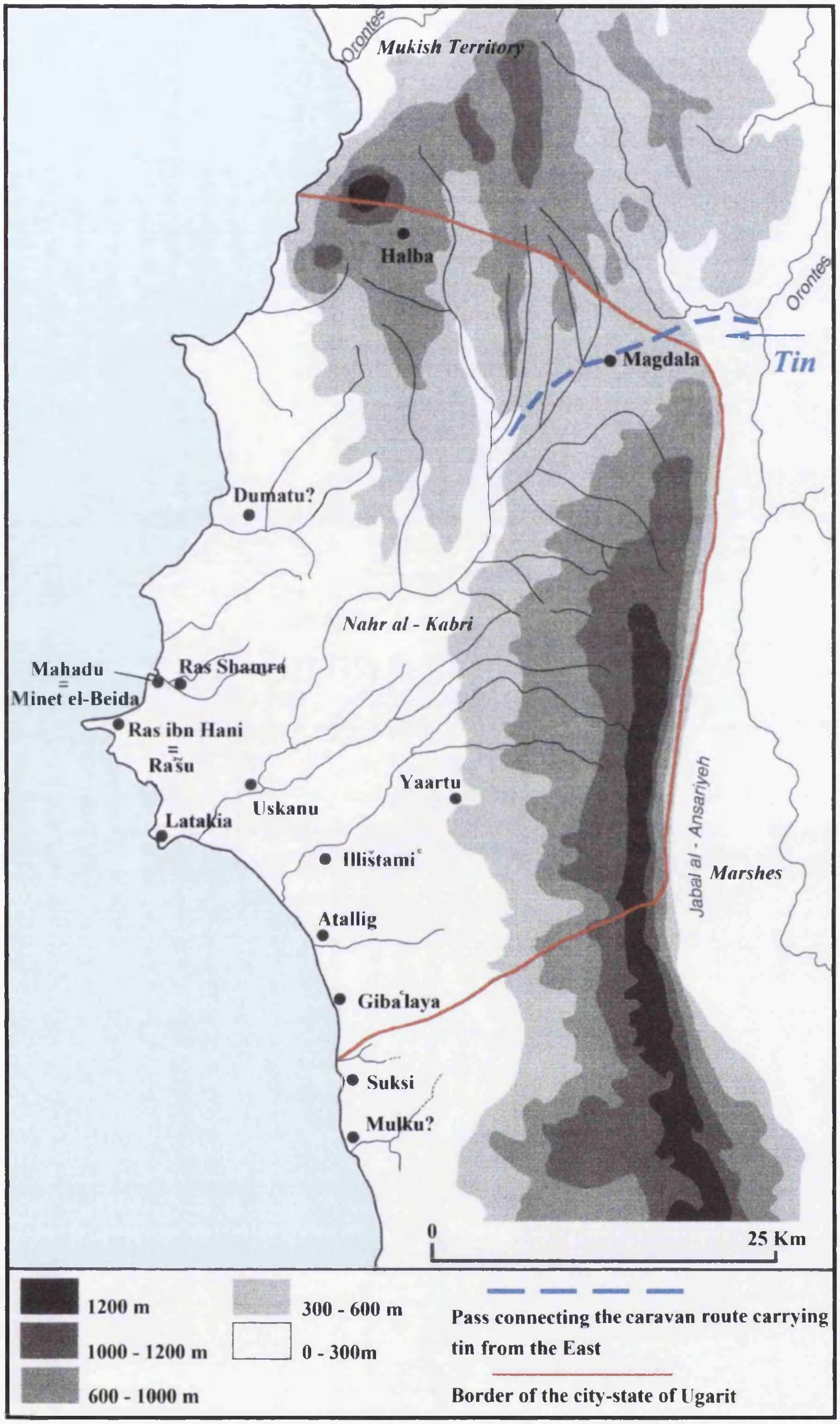



**Figure 6.44: Topographical map of Ugarit, with high hills to the north and east providing protection.**
Adapted from Yon 2006: 11, Figure 6

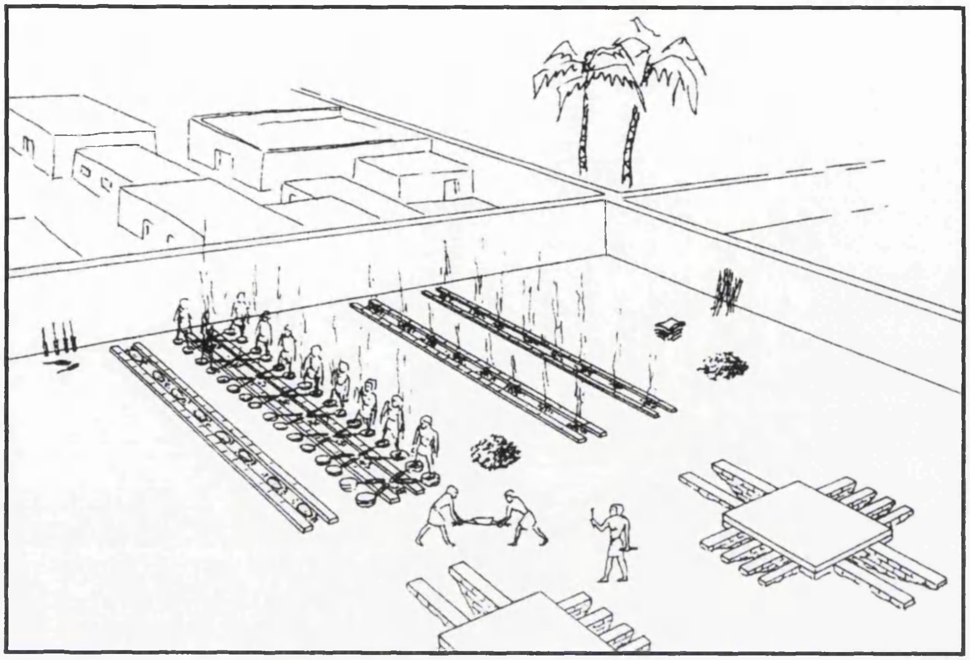


**Figure 6.45: Reconstruction of the bronze-melting complex at site Q I, level B/3.**
After Rehren et al 1998: 230, Figure 2.

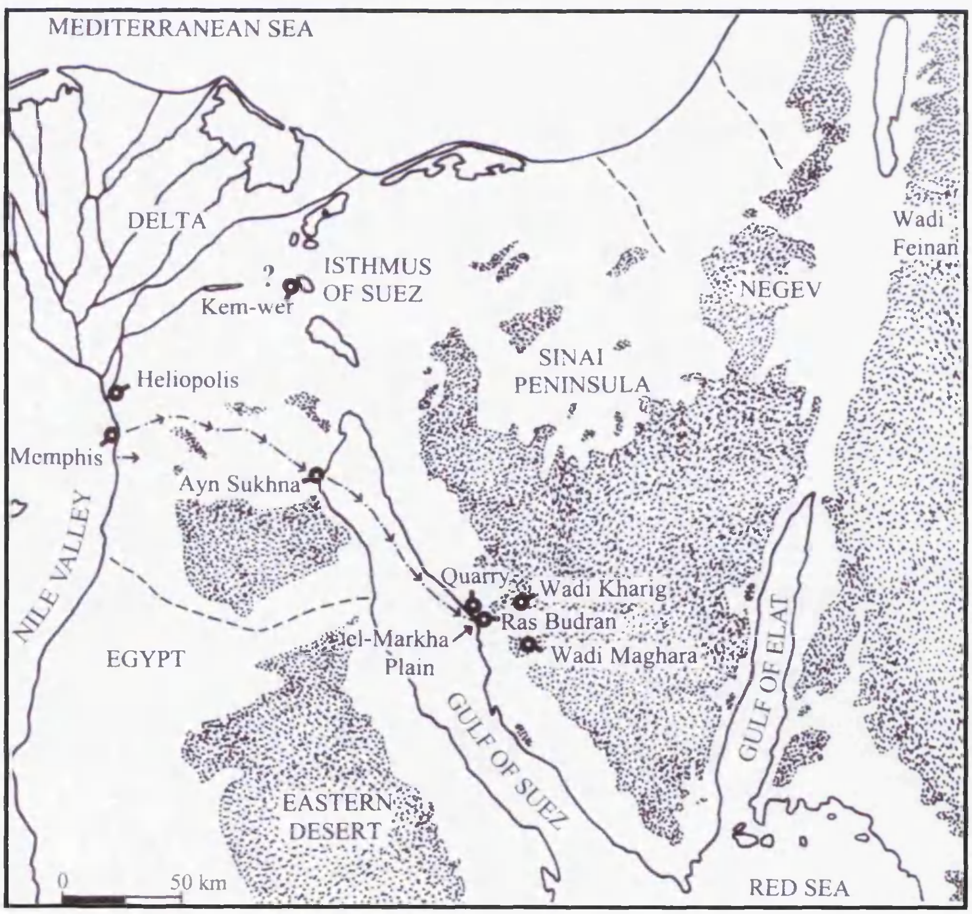



**Figure 6.46: Suggested route from Memphis to the quarries and copper/turquoise mines on the West coast of the Gulf of Suez, overland to Ayn Sukhna and then by boat across the Red Sea to Ras Budran.**
Mumford 2006: 14, Figure 1.

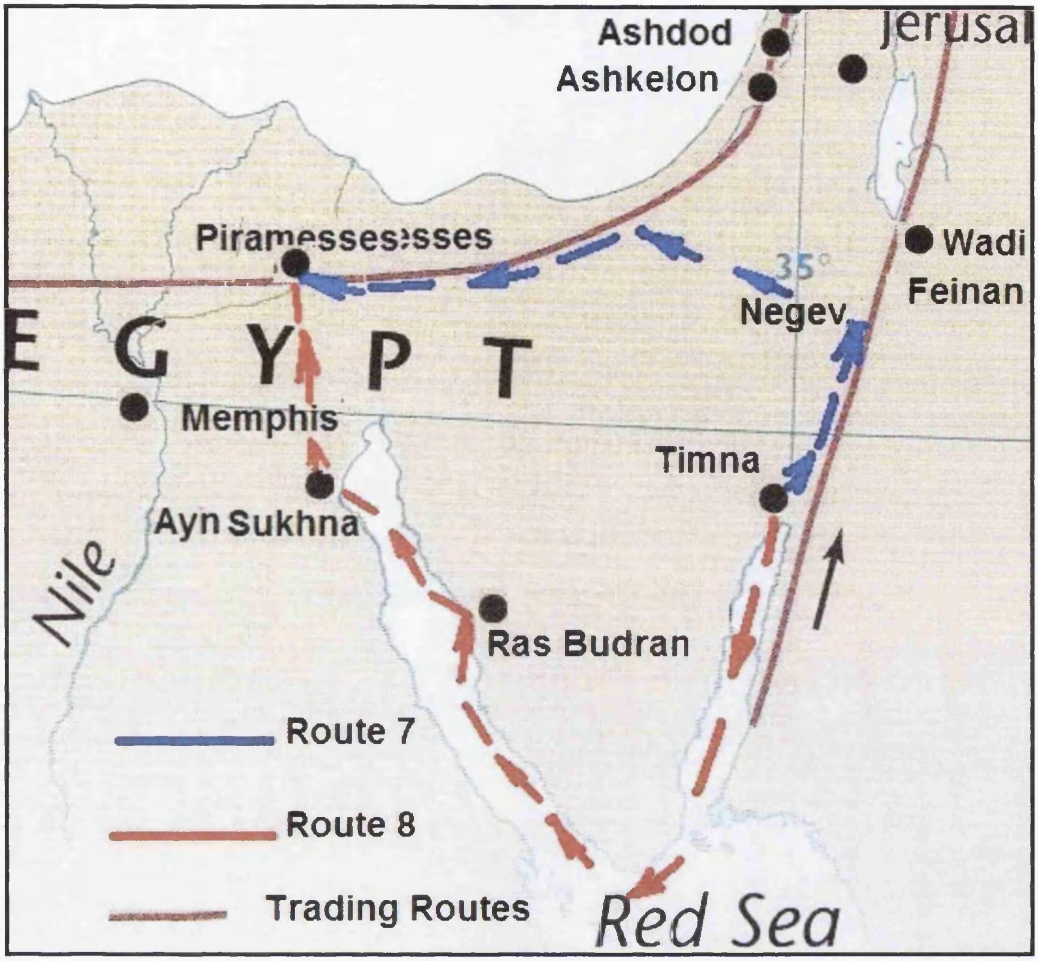



**Figure 6.47: Alternative routes to Timna from Piramesses.**

# Chapter 7 Figures: LBA Economy

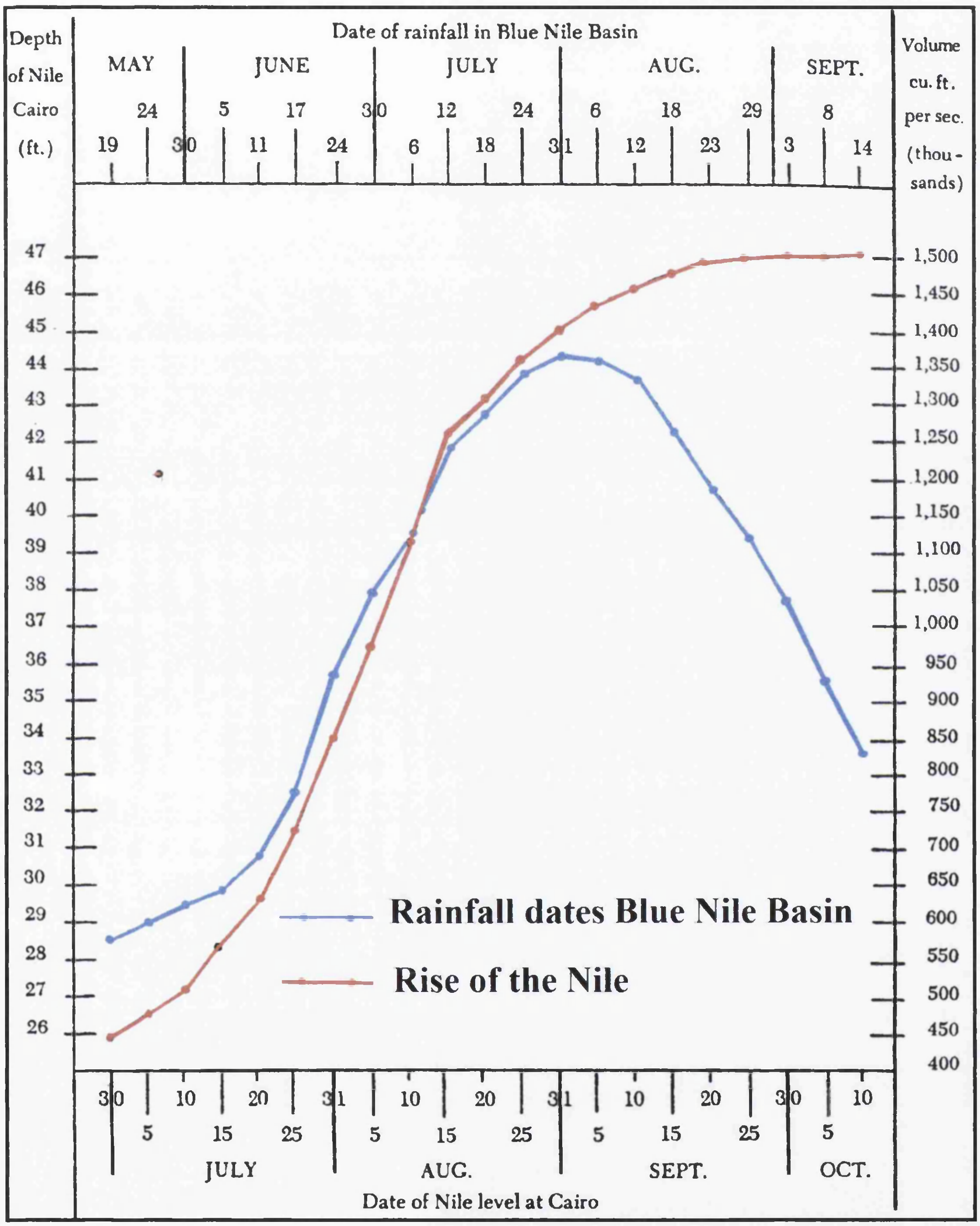



**Figure 7.1: Relationship between rainfall in Ethiopia in the Blue Nile Basin and the rise of the Nile at Cairo. The rainfall dates for the Atbara Basin lags by approximately five days.**
Adapted from Popper 1951: 256, Graph 6.

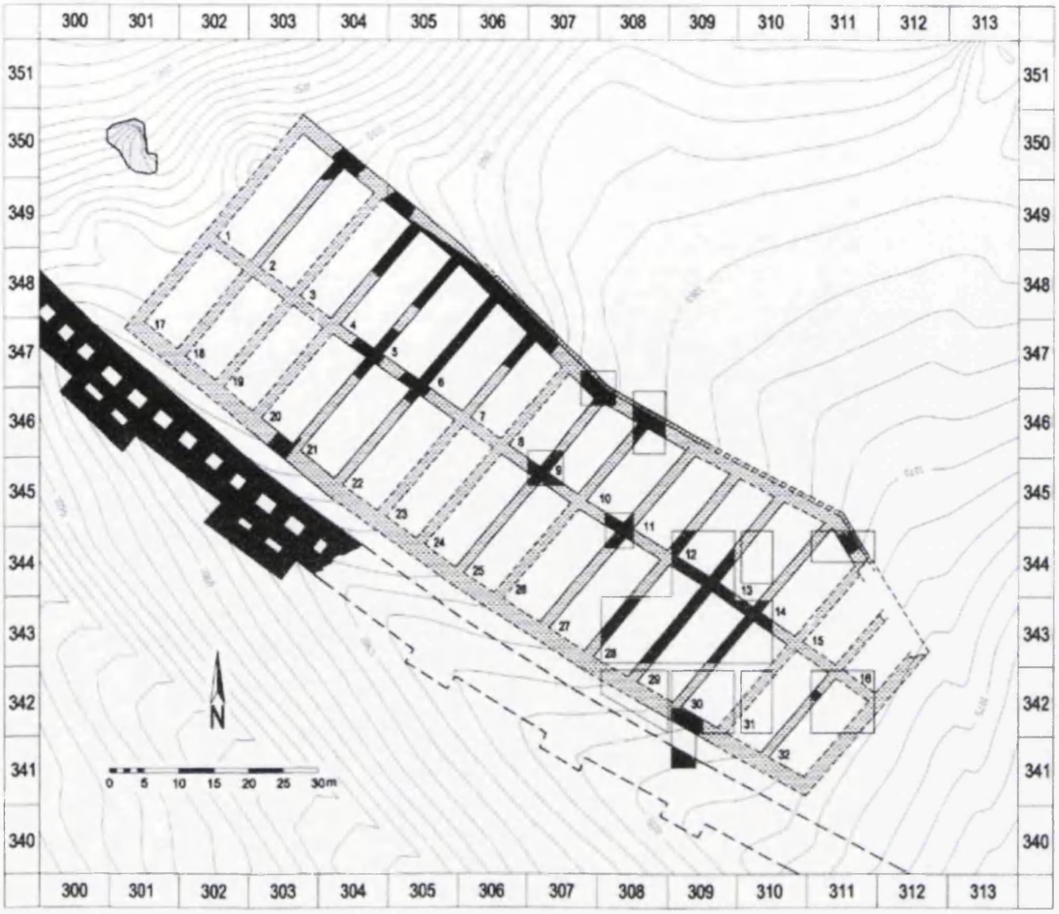



**Figure 7.2: Grain silos excavated within the Hittite capital of Hattusha.**
After German Institute of Archaeology, The Excavations at Hattusha, created 15/09/2002, last updated 26/6/2004, accessed 25/7/2006, available from http://www.hattuscha.de/eng/themen/05-forschung/silokomplex/forschung-silokomplex.htm.

**Figure 7.3: Egyptian plough with bronze tip to the plough ard.**
Author's photograph. Berlin Ägyptisches Museum.

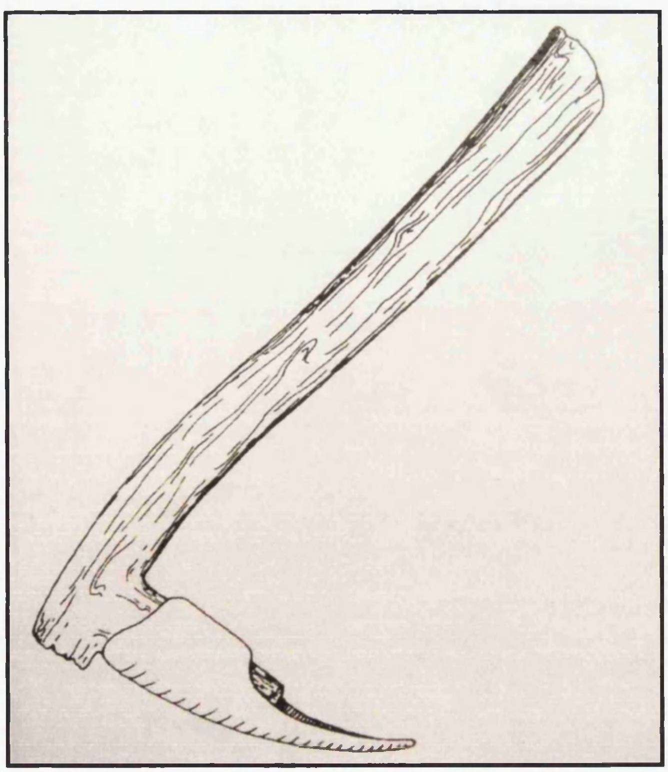


**Figure 7.4: Scrap bronze hoe head found on the Gelidonya wreck.**
After Bass 1962: 93, Figure 106.

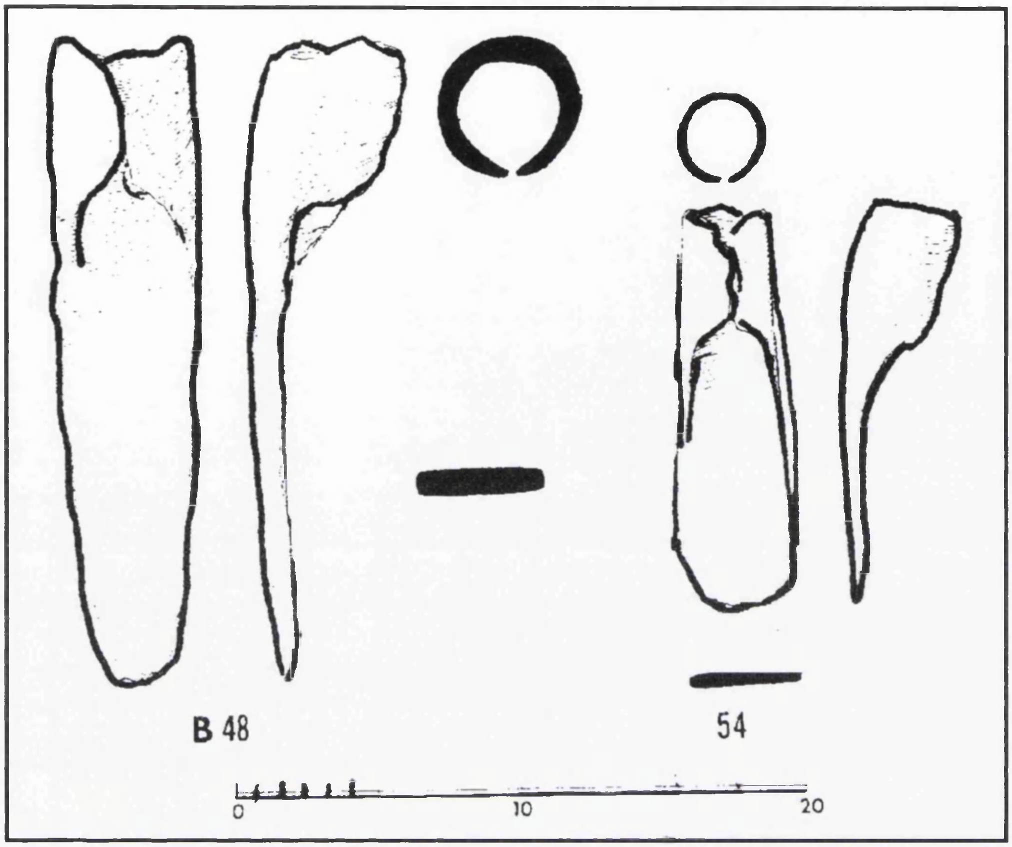



**Figure 7.5: Bronze plough and hoe head excavated from the Gelidonya wreck.**
After Bass 1967: 89, Figure 102.

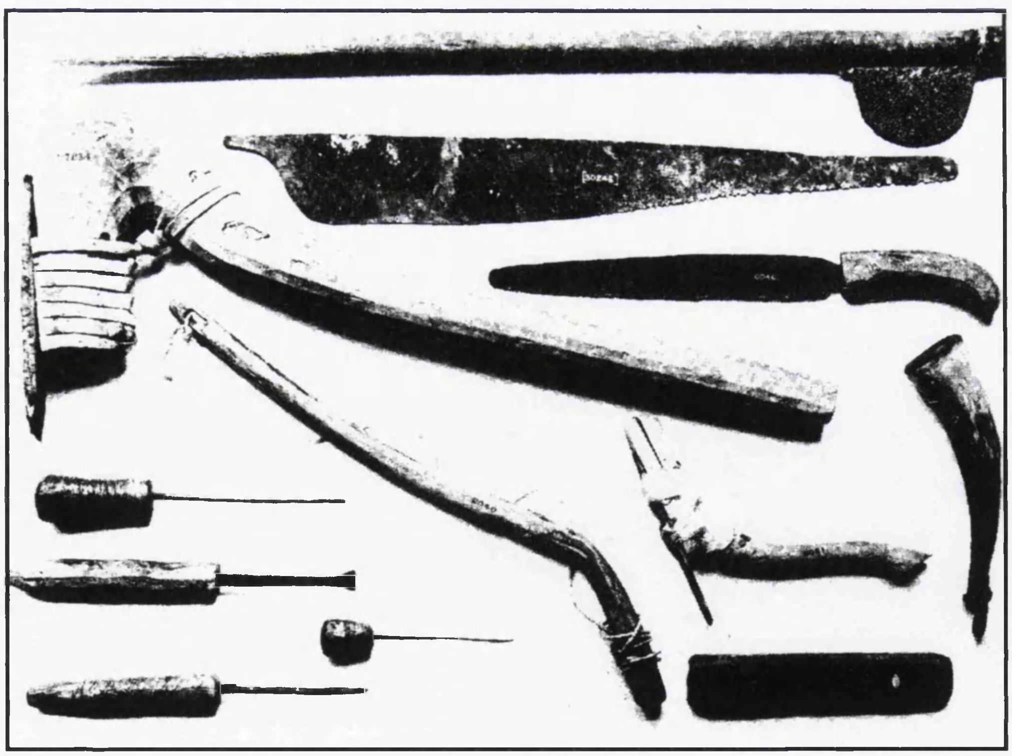


**Figure 7.6: Set of carpenters bronze tools from an unknown Theban Tomb consisting of axe, pull saw, adzes, chisels, bradawls, and a bow drill. On display in the British Museum, London. Accession numbers 6037, 6040, 6042-44, 6046, 6055, 6061, 22834, 30083, 30245, and 36728.**
After Stead 1986: 37, Figure 48.

**Figure 7.7: Replica of the Ulu Burun wreck.**
After Erkurt 2005: 328.

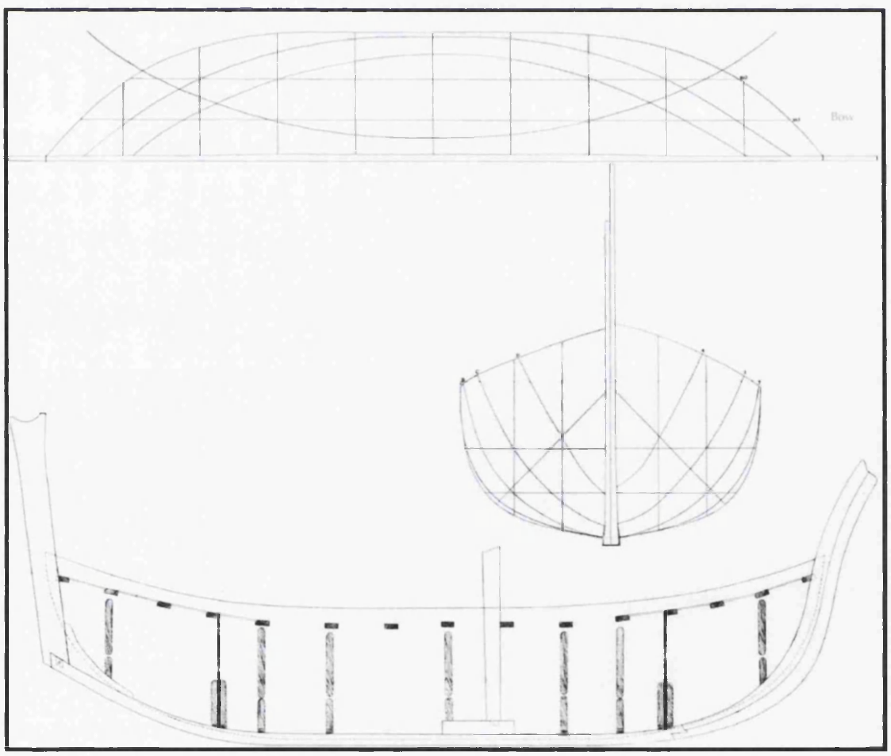


**Figure 7.8: Theoretical design of the Uluburun based on the archaeological record and the weight distribution of the goods carried. Note the incorporation of a keel that gave longitudinal rigidity.**
After Linn 2003: 17, Figure 1.8.

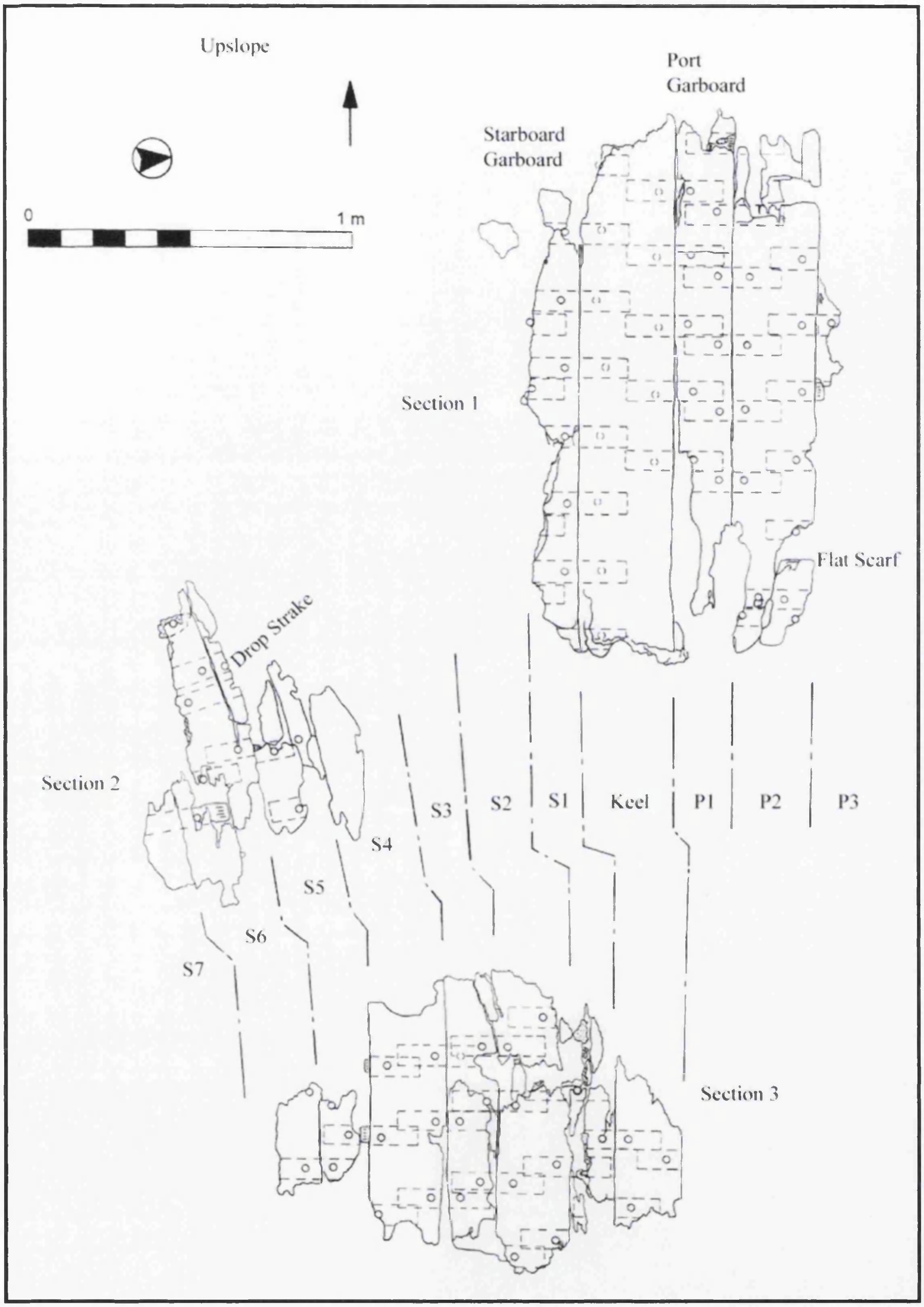



**Figure 7.9: Preserved sections of the Ulu Burun hull showing mortise and tenon construction to join the hull planks together and secured with round dowels.**
After Linn 2003: 10, Figure 1.4.

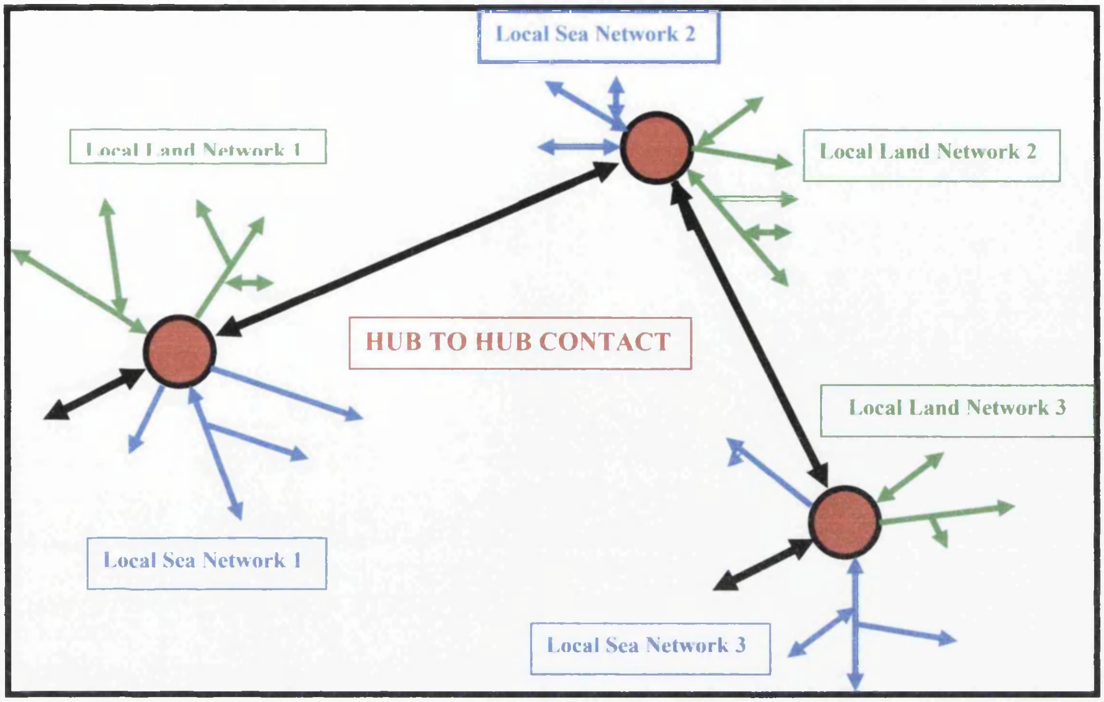



**Figure 7.10: Relationship of sea hubs to local trading networks.**

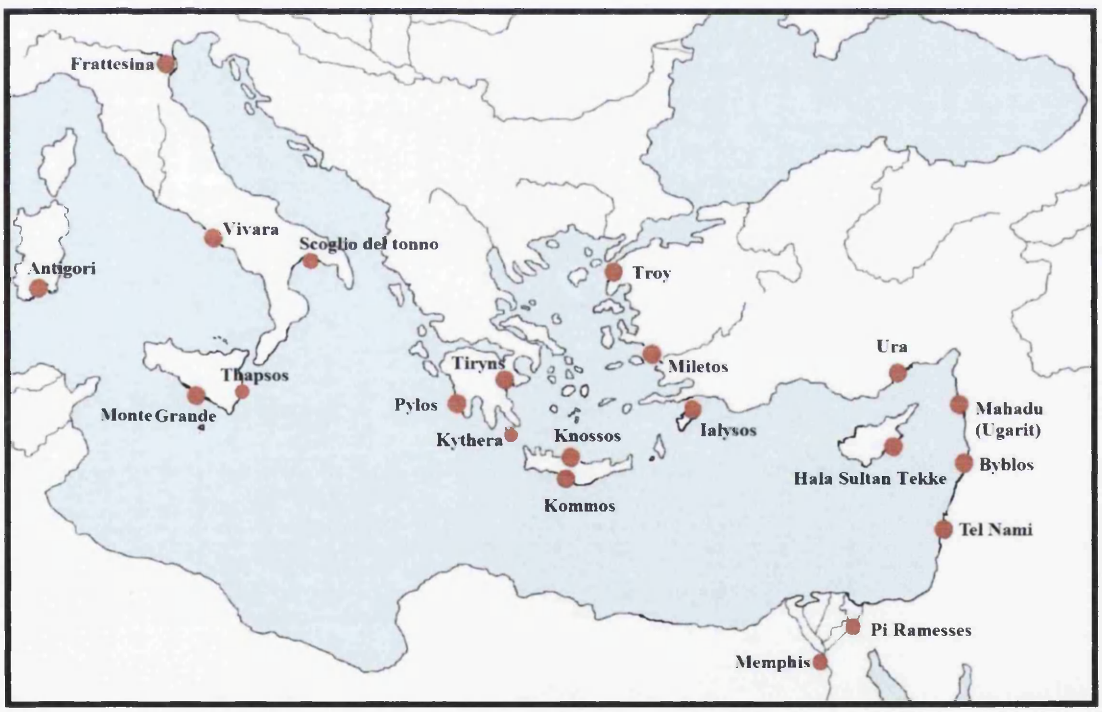



**Figure 7.11: Proposed coastal sea hubs in the Central and Eastern Mediterranean based on the LBA archaeological and textual record.**

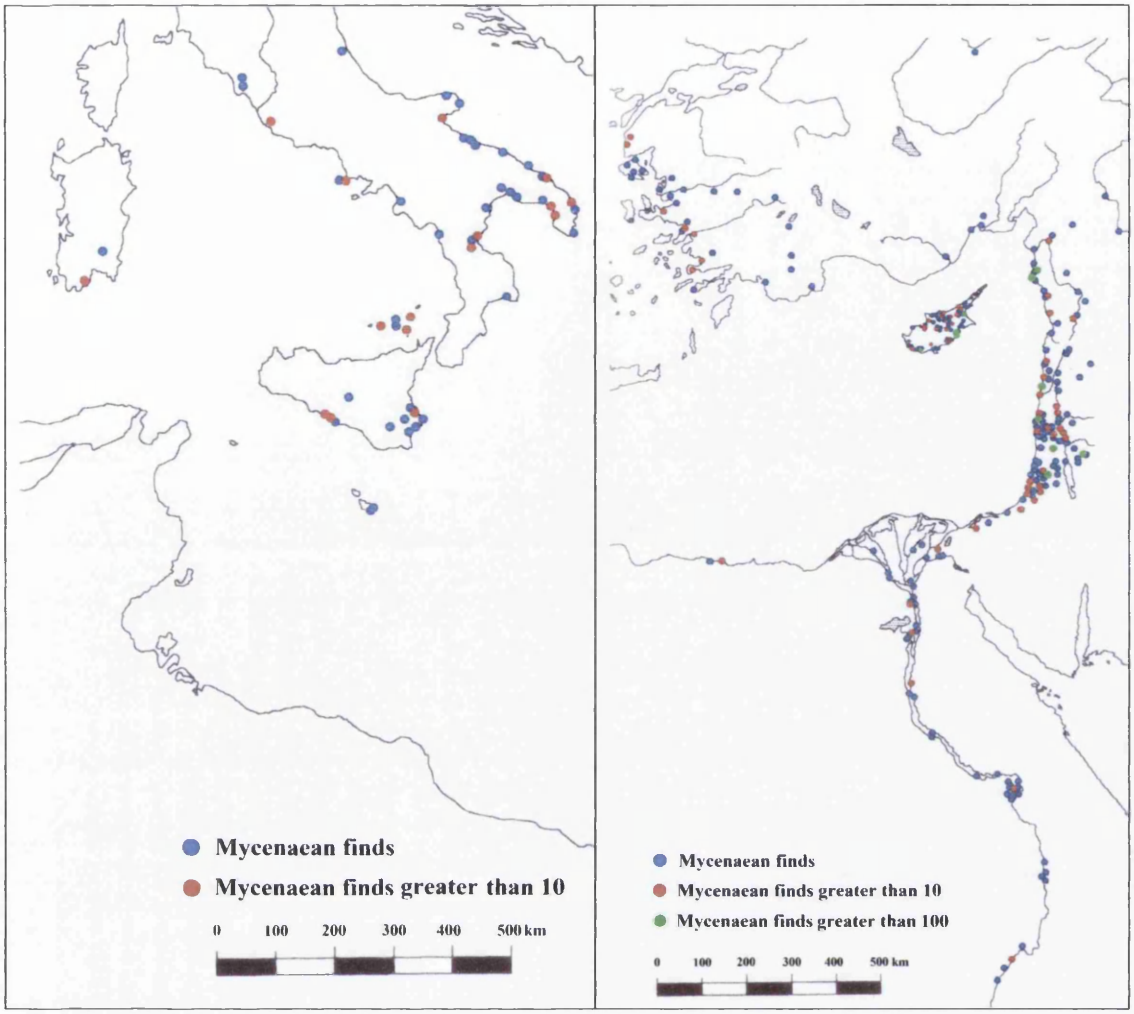



**Figure 7.12: Widespread distribution of Mycenaean pottery found in the archaeological record of Central and Eastern Mediterranean.**
Source data combined from van Wijngaarden 2002, Leonard 1994, Vagnetti 1993; 1999b and Vianello 2005.

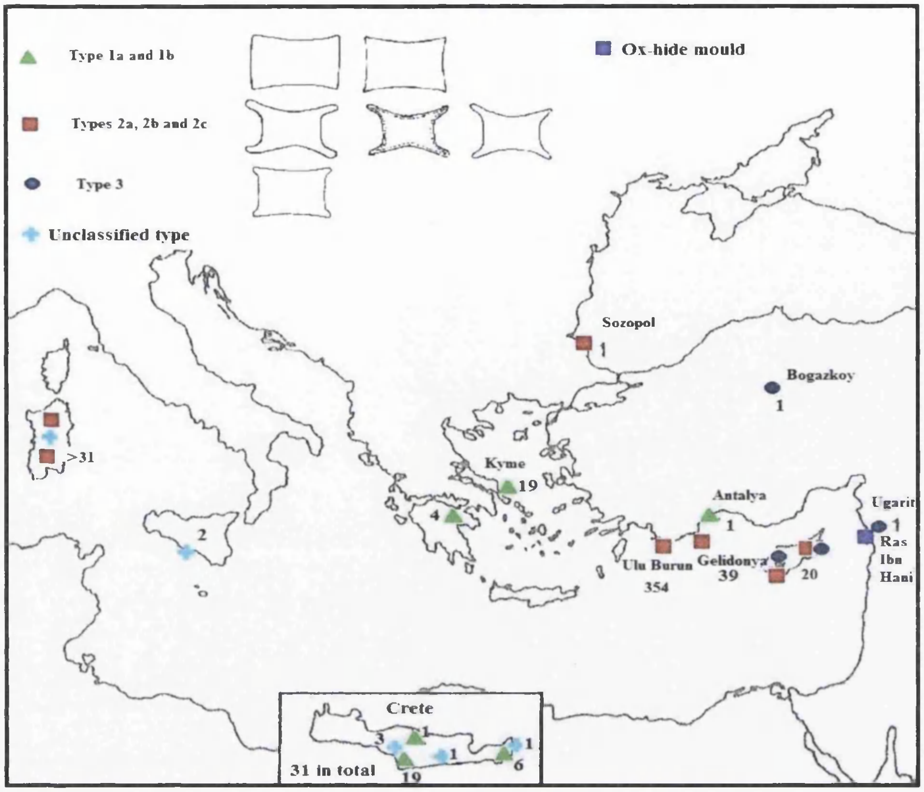



**Figure 7.13: Distribution of oxhide ingots found in the archaeological record and collated using Buchholz typology (see ahead Figure 7.19).**
Gale 1989: 248, Figure 9 and Buchholz 1957: 7.


**Figure 7.14: Sites where Cypriot White Slip and pithoi have been found in the archaeological record showing its widespread dispersal across the Central and Eastern Mediterranean.**
Adapted from Matthäus 2005 : 346-347 abb. 23-24.

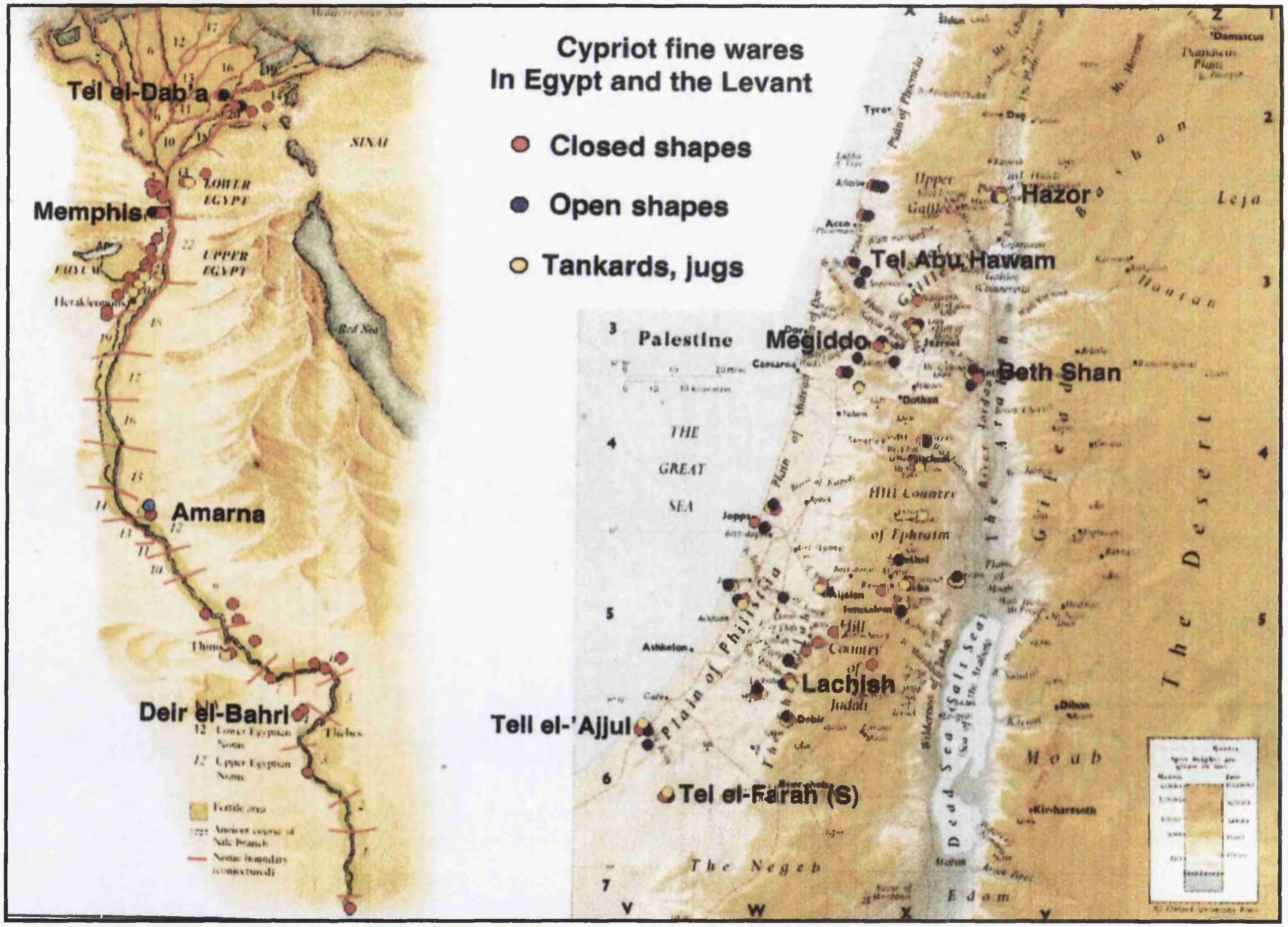



**Figure 7.15: Distribution map of Cypriot fine ware pottery in Egypt and the Levant.**
After Hulin 2006: 158, Map 1.

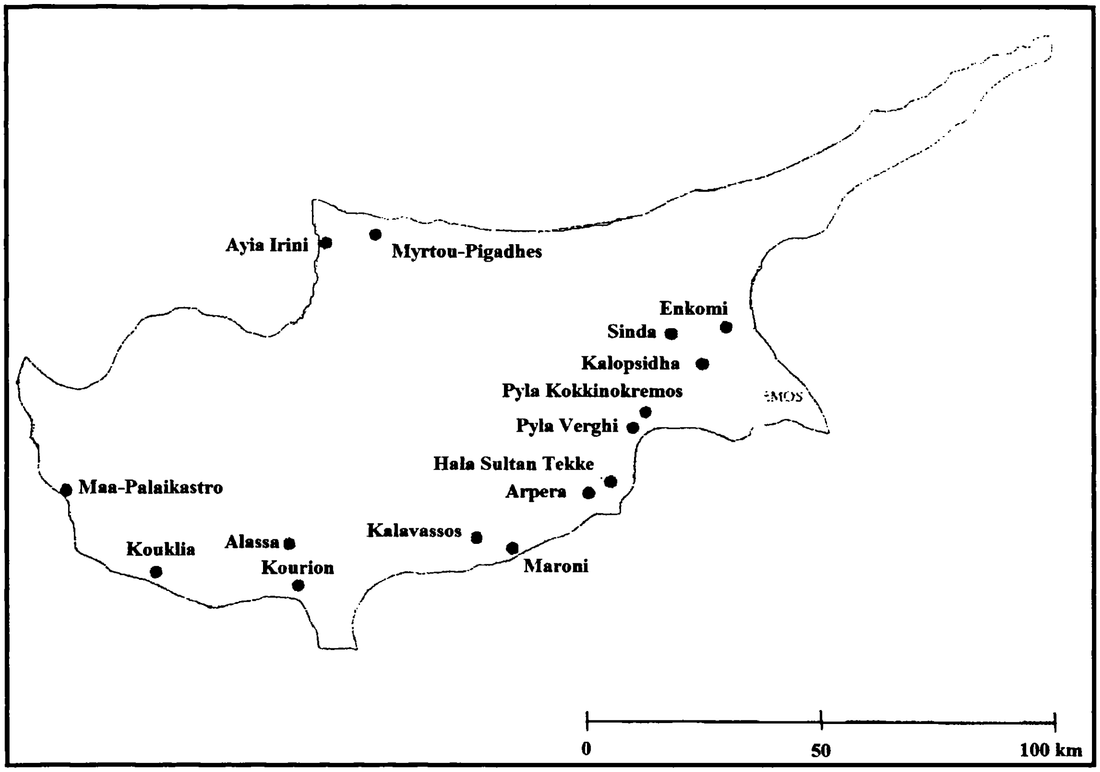



**Figure 7.16: Find spots of Canaanite jars in Cyprus.**
Adapted from Leonard 1995: 248 Figure 15.3.

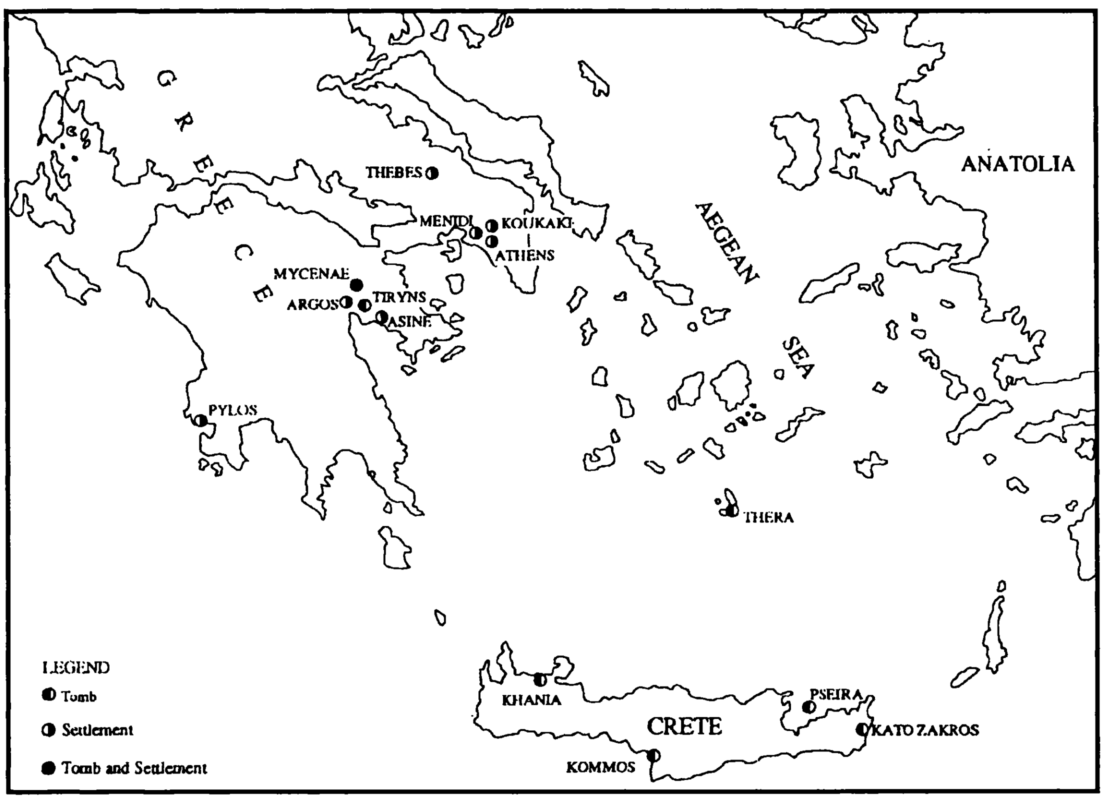



**Figure 7.17: Find spots of Canaanite jars in the Aegean.**
After Leonard 1995: 247 Figure 15.2.

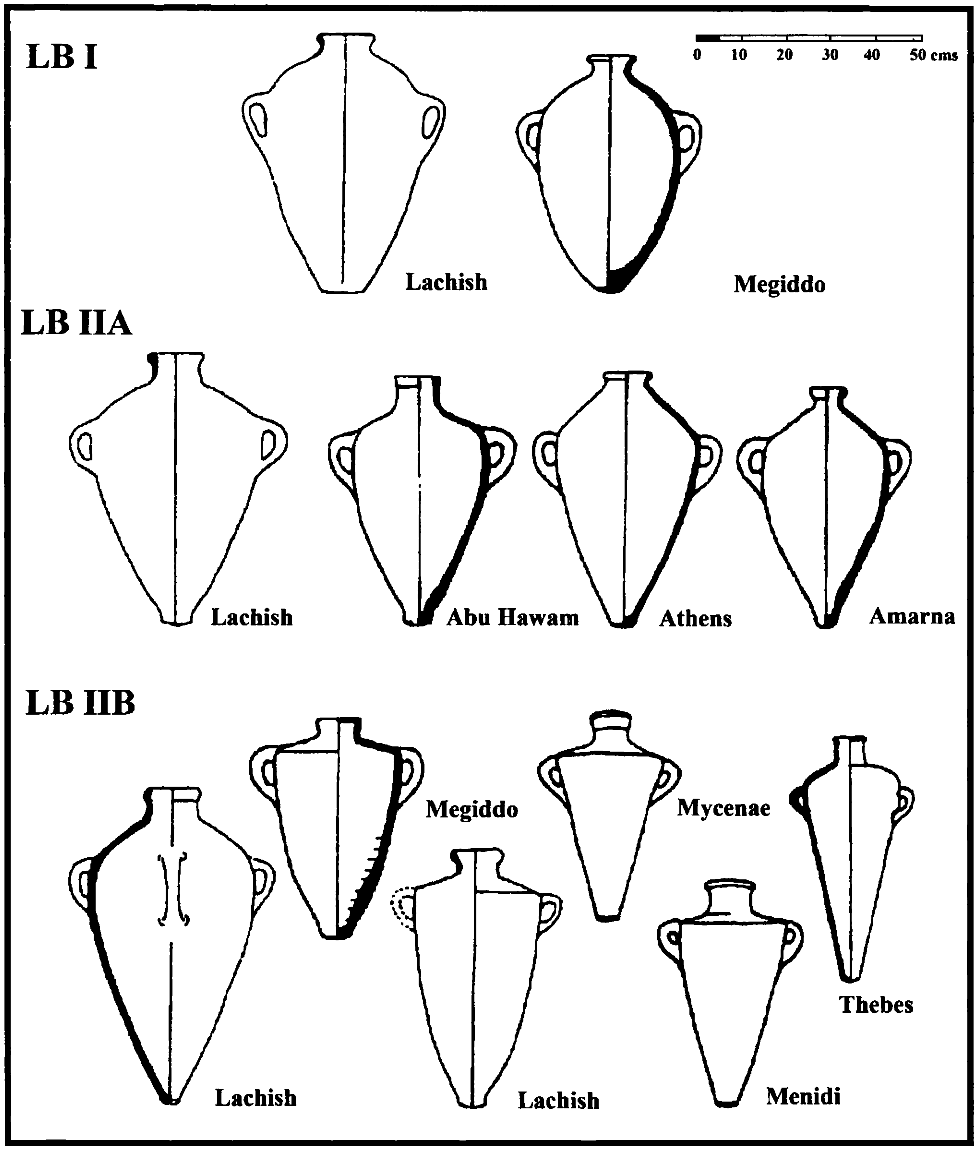



**Figure 7.18: Canaanite "Commercial" Jar Typology.**
After Amiran 1969 : 139 and Museum Für Unterwasserarchäologie Bodrum Inv. No. 60-31.84

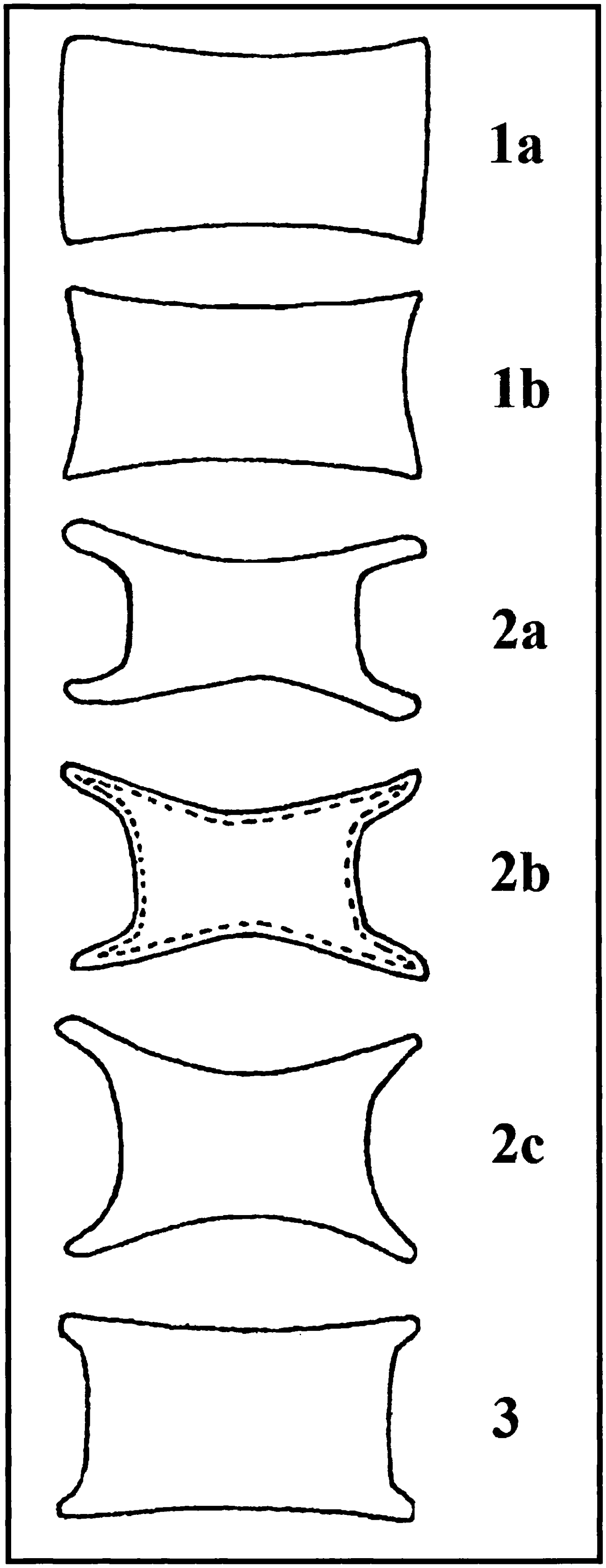



**Figure 7.19: Standardised shapes of LBA Copper Ingots.**
Adapted from Buchholz 1957: 7.

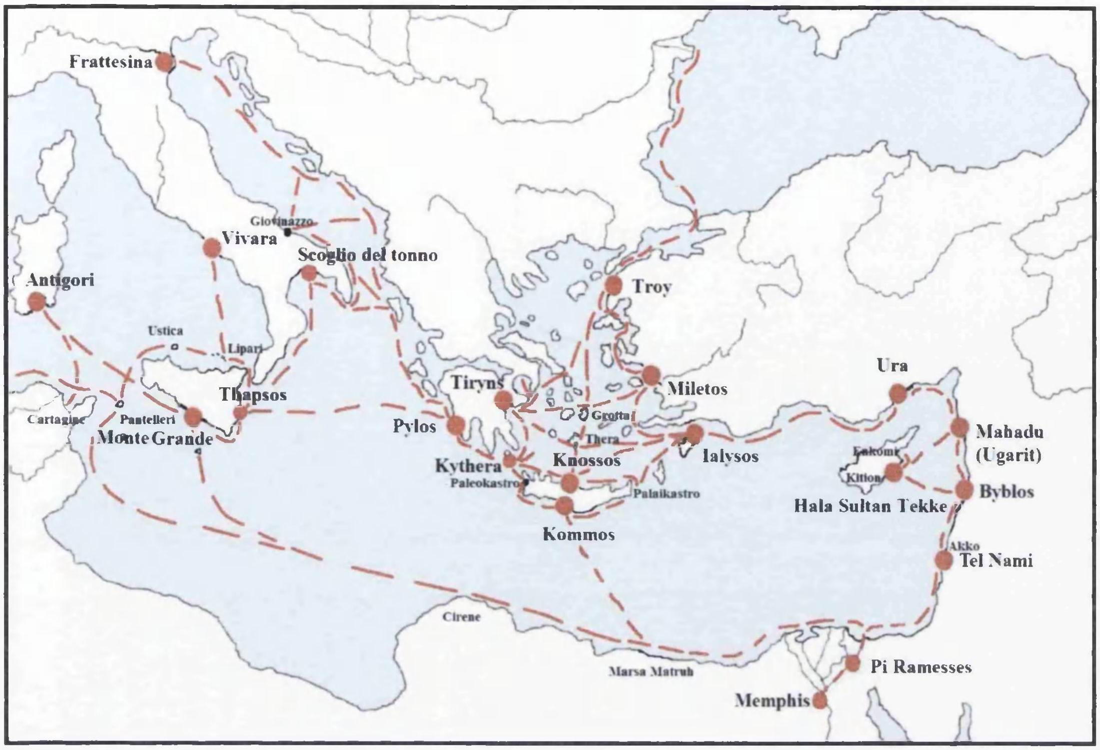



**Figure 7.20 Possible network of trade routes in the LBA.**

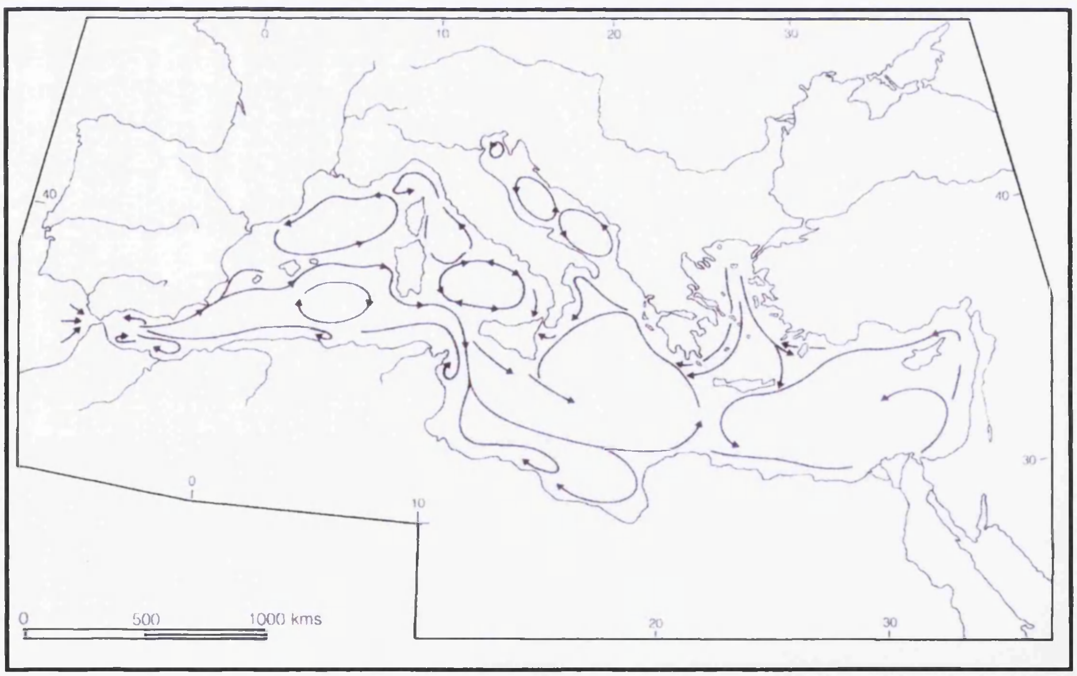



**Figure 7.21: The prevailing currents in the Mediterranean basin that encourages anticlockwise routes for sailing vessels.**
Agouridis 1997: 4, Figure 1.

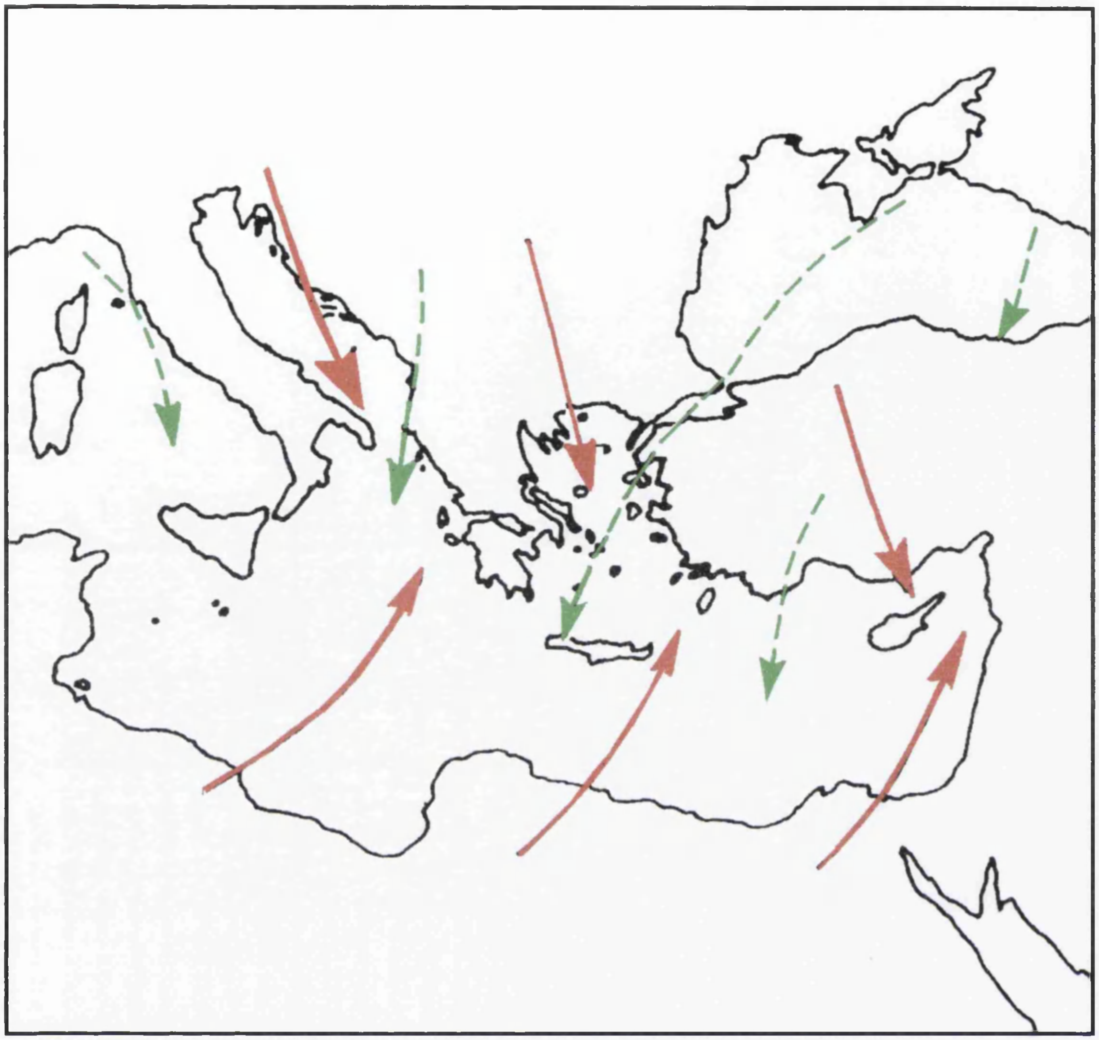


**Figure 7.22: Prevailing winter and summer winds. The green arrows represent the summer winds that favour an anticlockwise direction for sailing boats. The red arrows represent two wind systems: the northerlies (Boreas and kindred winds) and southwesterlies (the Sirocco and kindred winds).**

After Morton 2001: Figure 23.

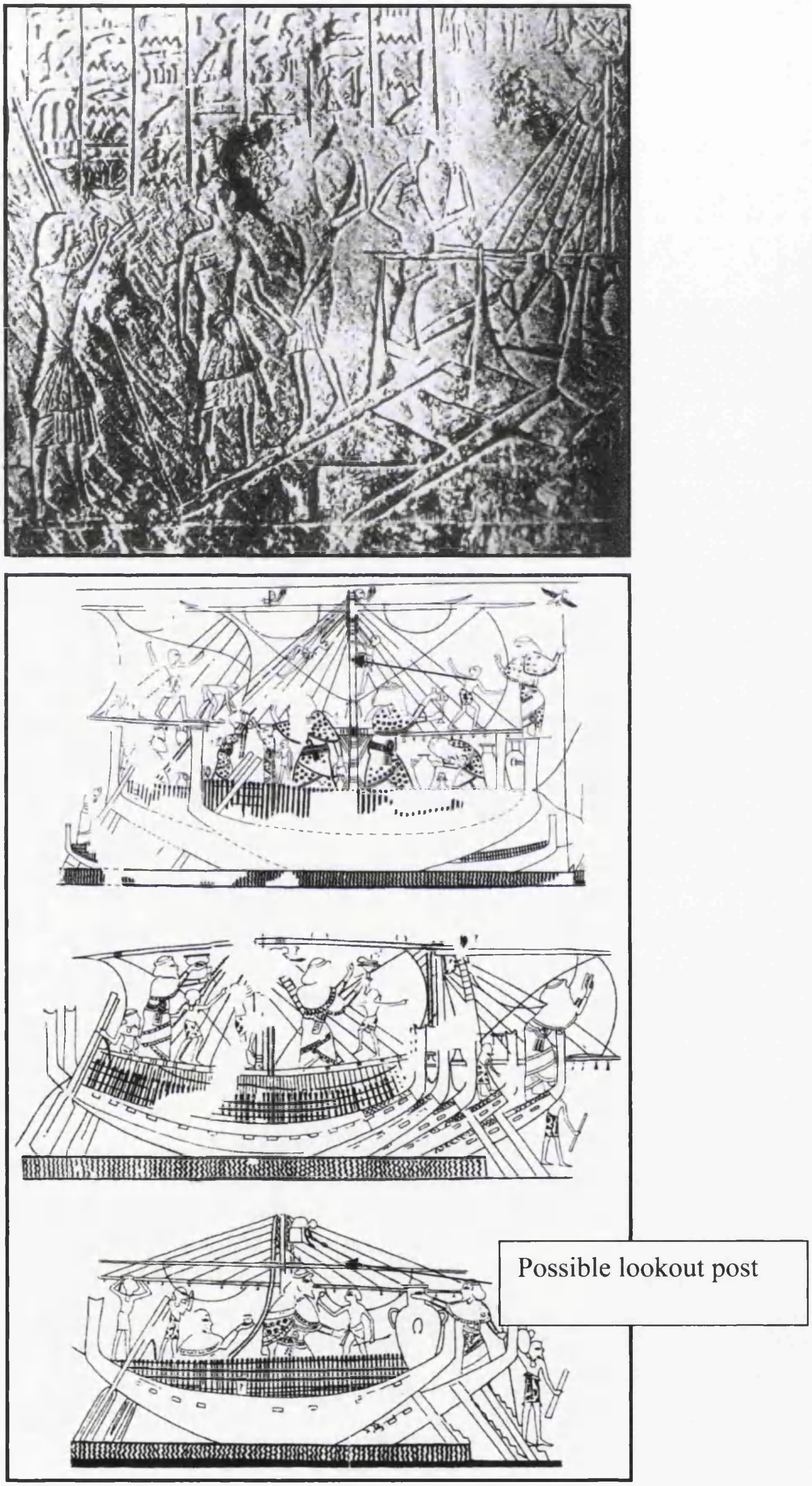



**Figure 7.23: Possible Syrian ships portrayed in the tomb paintings of Iniwia and Kenamun.**
Iniwia tomb after Wachsmann 1998: 56, Figure 3.24. Kenamun tomb adapted from Wachsmann 1998, 43-4, fig. 3.4, and 3.5, and 3.6.

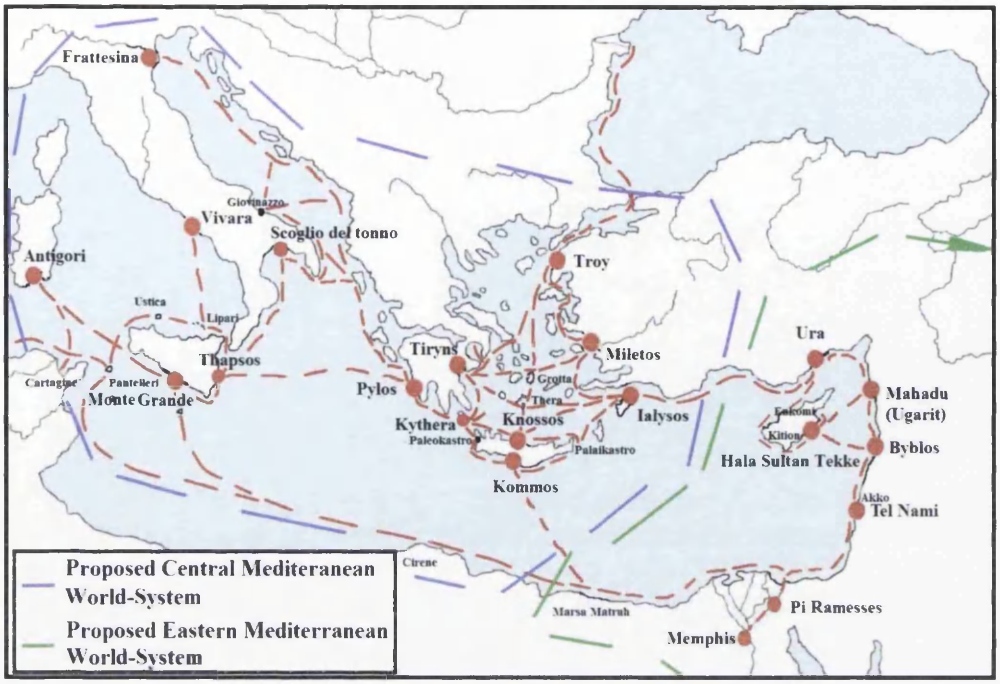



**Figure 7.24: Proposed Central and Eastern World System.**

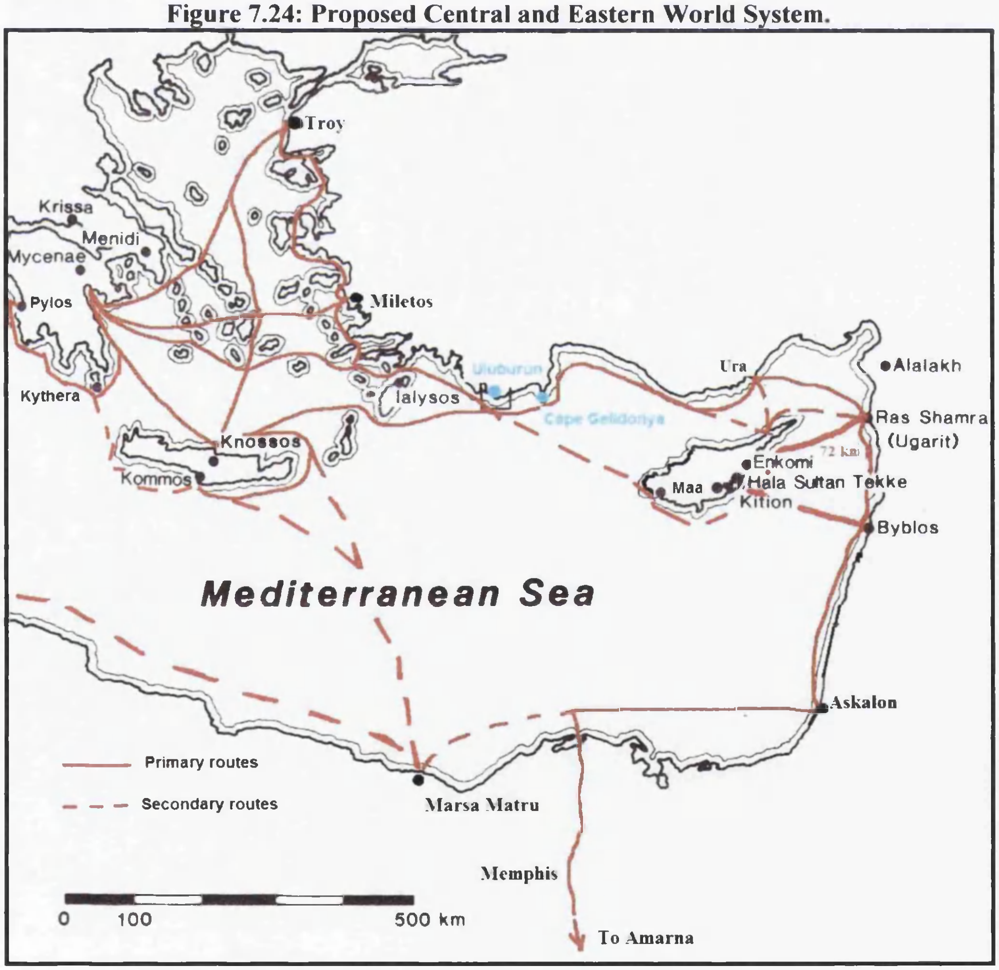



**Figure 7.25: The geographic position of Cyprus made it well positioned to take part in trading activities being only 72 km from Ugarit.**

**Figure 7.26: Cypriot pottery excavated from the Ulu Burun wreck.**
Adapted from Yalçin 2005: 586-587.

A Merchant's Balanced Account and Neosumerian Gold 201

FLP 558

| Ledger Heading | Quantity | Commodity | Value (kù-bi) Minas | Value (kù-bi) Shekels | Value (kù-bi) Grains | Totals Minas | Totals Shekels | Totals Grains | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| | 3 minas 31 shekels 56 grains | silver | (3 | 31 | 56) | | | | credit balance |
| | 2 minas | silver | (2 | -- | --) | | | | silver of Ur-ninsu, the merchant |
| | 1 mina | silver | (1 | -- | --) | | | | silver of Lukalla |
| | 40 shekels | silver | (- | 40 | --) | | | | silver of Ur-e'e |
| | 10 talents | wool | 1 | -- | -- | | | | via the ensi (of Umma?) |
| | 180 gur | barley by gur | 3 | 45 | -- | | | | from the threshing floor of Kamari |
| | 7 gur 240 sila | barley by gur | -- | 9 | 135 | | | | še-si-ki 11th month (from Ur-dumuzida?) |
| | 32 talents | wool | 3 | 12 | -- | | | | second (delivery from Ur-dumuzida?) |
| | 9 shekels 72 grains | kù zú-lum-ma | (- | 9 | 72) | | | | (belonging to) Ur-pau'e (all the foregoing) from Lukalla |
| sub-total | 15 mina 27 shekels 83 grains | silver | | | | 15 | 27 | 83 | (capital on deposit) |
| out of which | 1 shekel | 7 "carat" gold | -- | 7 | -- | | | | |
| | 11 shekels | silver | (- | 11 | --) | | | | (for) the standard of the ensi |
| | 2 minas | silver | (2 | -- | --) | | | | first (purchase) |
| | 1 mina | silver | (1 | -- | --) | | | | second (purchase) |
| | 3 shekels 173 grains | 16 "carat" gold | 1 | 3 | 68 | | | | |
| | 19 shekels 120 grains | 17 "carat" gold | 5 | 34 | 60 | | | | |
| | 1 mina | silver | (1 | -- | --) | | | | KÙ.GI-ta gur-ra (all the foregoing) Lukalla received |
| sub total | 10 minas 55 shekels 128 grains | silver | | | | 10 | 55 | 128 | was withdrawn |
| differ-ence | 4 minas 31 shekels 135 grains | silver | | | | 4 | 31 | 135 | balanced account of Ur-dumuzida the merchant |
| | Month of the harvesting (Umma I) Year the chair of Enlil was made (AS 3) | | | | | | | | |

**Figure 7.27: Silver balance account.**
After Young 1979: 201.

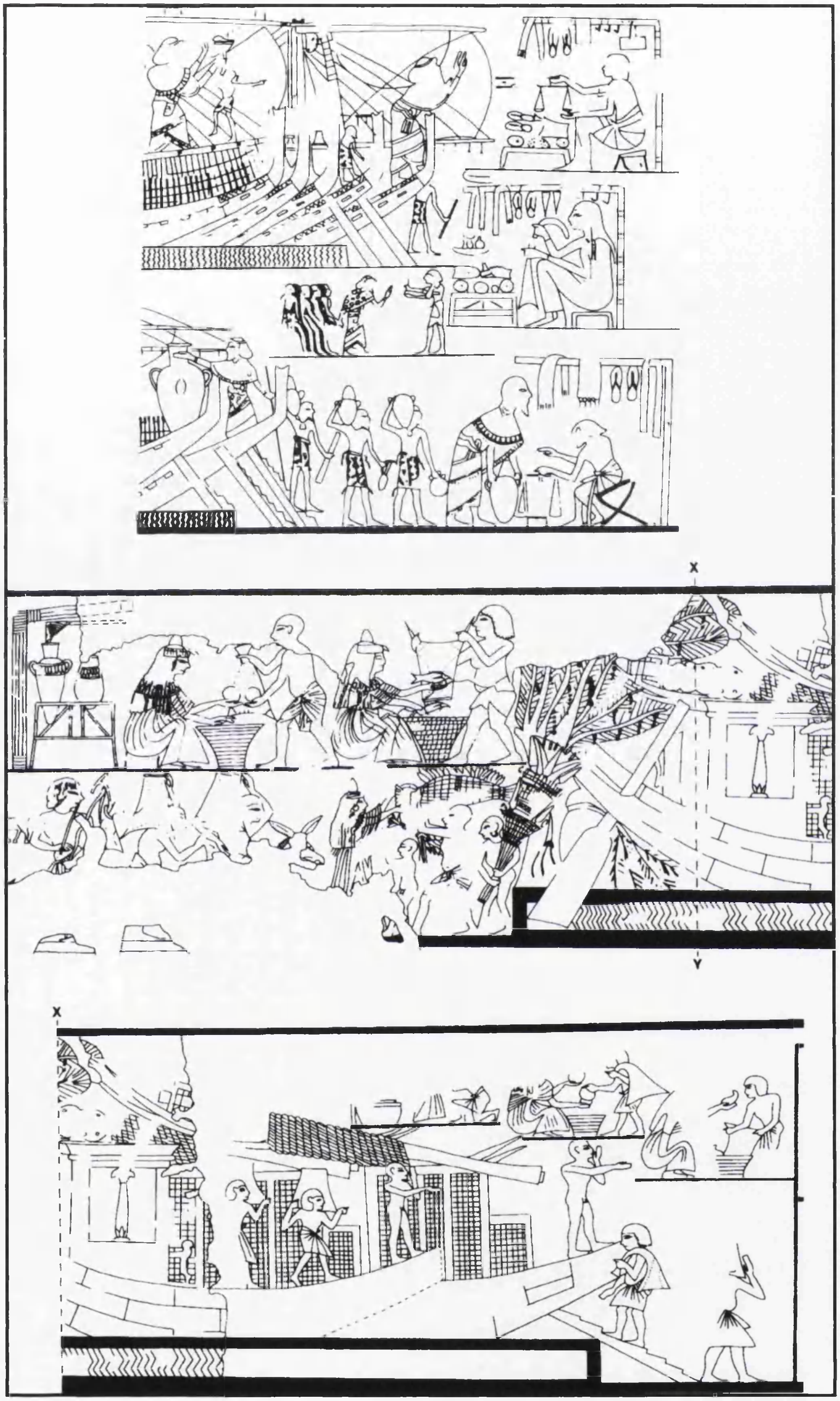



**Figure 7.28: Market place scenes by the river from the tombs of Kenamun and Ipy.**
After Kemp 1991: 254, Figure 86 with full references.

# AGCALC SPEADSHEET

# Module 1: Summaries

**Report 3.1a: Hierarchy of needs summary**

| Region | Egypt | Cyprus |
|---|---|---|
| **100,000 population sample** | **100,000** | **100,000** |
| Domestic shelter to satisfy popl'n growth | 920 | 920 |
| Domestic pottery | 66 | 66 |
| Agrarian workforce | 37,205 | 47,490 |
| Cloth workforce | 14,659 | 10,430 |
| Non-productive 55+ & under 6 | 30,860 | 30,860 |
| Elite | 2,970 | 2,970 |
| **Tot state supported value add workforce** | **13,320** | **7,264** |
| **Non value add workforce** | **86,680** | **92,736** |

| | | |
|---|---|---|
| % of GDP equated to value add workforce | **13.3** | 7.3 |
| Non Agrarian | **62,795** | **52,510** |
| % of value add workforce of working adults | **20.1** | **11** |

**Report 3.1b: Population allocated by basic needs, added value, and non productive**

| Allocation of manpower/ 100,000 population | Egypt | Cyprus |
|---|---|---|
| Housing to satisfy population growth | 920 | 920 |
| Domestic pottery | 66 | 66 |
| Agriculture | 37,205 | 47,490 |
| Clothing | 14,659 | 10,430 |
| **Total workforce supporting basic needs** | **52,850** | **58,906** |
| **Allocation of manpower/ 100,000 population** | **Egypt** | **Cyprus** |
| Total workforce supporting basic needs | 52,850 | 58,906 |
| Non-productive (age 0-6 or +55) | 30,860 | 30,860 |
| Elite socio-economic groups 1-3 | 2,970 | 2,970 |
| Workers for state projects & production of value-add goods | **13,320** | **7,264** |
| **Total** | **100,000** | **100,000** |

**Population assumptions (see SHELTER spreadsheet)**

| | | | | | | | **Low case for Cypriot added value for pop of 150,000** | **High case for Cypriot added value for pop of 200,000** |
|---|---|---|---|---|---|---|---|---|
| Total population of Egypt | 2.2 | million | Ratio Egypt to Cyp. | 27 | Egyptian non-basic workforce | **293,000** | | |
| Total population of Cyprus (low) | 150,000 | Total population of Cyprus (high) | | 200,000 | Cypriot non-basic workforce (min) | **10,900** | | |
| | | Cypriot non-basic workforce (max) | | 14,528 | % Egyptian non-basic workforce | **27** | **10,900** | **14,528** |

**Report 3.1c: Sumary of agrarian area of land under cultivation for staples to support 100,000 population**

| Total energy requirements of 100000 people | | 86,065 | Million kcals/100,000 population | |
|---|---|---|---|---|
| **Yield** | | **Yield Kg/ha marginal land by food type** | **Yield Kg/ha average land by food type** | **Yield Kg/ha best land by food type** |
| **Cyprus** | Barley | 408 | 660 | 1073 |
| | Emmer wheat | 399 | 714 | 1455 |
| | Pulses and vegetables | 455 | 563 | 802 |
| **Egypt** | Barley | 703 | 1057 | 1313 |
| | Emmer wheat | 687 | 1156 | 1395 |
| | Pulses and vegetables | 917 | 1582 | 1781 |
| **Sowing rate** | | 1 to 10 | 10 | % |
| **Wastage rate** | | 1 to 6.7 | 15 | |

| **Total area ha under cultivation for food and fodder** | **Case a ploughing. Fodder required for plouging and transport of harvest** | **Case b hoeing. Fodder required only for transport** |
|---|---|---|
| Cyprus: Area of land for staples ha | 69,342 | 69,342 |
| Cyprus: Area of land for fodder ha | 10,018 | 1,073 |
| **Total** | **79,360** | **70,415** |
| Egypt: Area of land for staples ha | 37,834 | 37,834 |
| Egypt: Area of land for fodder ha | 21,825 | 2,147 |
| **Total** | **59,659** | **39,981** |

| | **% calories supplied by fodder** | |
|---|---|---|
| | Fodder required to be grown | Fodder supplied by grazing and straw |
| Cyprus | 15 | 85 |
| Egypt | 35 | 65 |

| **Total utilised agrarian manpower required to grow all crops** | **Case a ploughing. Fodder required for plouging and transport of harvest** | **Case b hoeing. Fodder required only for transport** | **Total utilised agrarian manpower required to grow all crops for different ratios of land worked by ploughing or hoeing** | |
|---|---|---|---|---|
| Cyprus man-years | 43,938 | 52,817 | Assume 60-40% split ploughing/hoeing | **47,490** |
| Egypt man-years | 36,298 | 37,593 | Assume 30-70% split ploughing/hoeing | **37,205** |

**Report 3.1d: Manpower required to feed one nuclear family**

| | **Cyprus** | **Egypt** |
|---|---|---|
| People working on the land | 47,490 | 37,205 |
| People not working on the land | 52,510 | 62,795 |
| Total Population | 100,000 | 100,000 |
| Size of nuclear family | 5.59 | 5.59 |
| No. of families/100,000 population | 17,889 | 17,889 |
| Man-years to feed a family | 2.7 | 2.1 |
| Area of land ha/family | 3.9 | 2.1 |

**Report 3.1e: Number of non-agrarian workers + dependents**

| | **Egypt** | **Cyprus** |
|---|---|---|
| Cloth,shelter/pottery workers + elite | 409,530 | 21,579 |
| Value-add + state infrastructure workers | 293,000 | 10,900 |
| Agrarian workers | 818,510 | 71,235 |
| Total active workers | 1,521,040 | 103,714 |
| Non-productive 55+ & under 6 | 678,920 | 46,290 |
| Total population | 2,199,960 | 150,004 |

# Calories required

**Report 3.2a: Calorie requirements (kcals) to stay healthy by body weight, Sex, age and the nature of work carried out**

| Sex | Wt kg | Age | Light work | Moderately active | Very active | Exceptionally active | Rates used in thesis |
|---|---|---|---|---|---|---|---|
| Child male and female | | 0 to 2 | N/A | N/A | N/A | N/A | 0 |
| Child male and female | | 2 to3 | N/A | N/A | N/A | N/A | 1,000 |
| Child male | 20.7 | 4 to 6 | 1,878 | | | | 1,878 |
| Child female | 20 | 4 to 6 | 1,790 | | | | 1,790 |
| Child male | 28.6 | 7 to 9 | 2,190 | | | | 2,190 |
| Child female | 27.6 | 7 to 9 | 2,110 | | | | 2,110 |
| Male Adolescent | | 10 to 12 | 1,830 | 2,400 | 2,600 | | 2,600 |
| Male Adolescent | 50 | 13-15 | | 2,800 | 3,037 | 3,237 | 3,237 |
| Female Adolescent | | 10 to 12 | 1,830 | 2,400 | 2,600 | | 2,600 |
| Female Adolescent | | 13-15 | | 2,600 | 3,037 | 3,237 | 3,037 |
| Male | | 16-19 | 1,830 | | 3,070 | 3,780 | 3,425 |
| Male | 65 | 20-39 | 2,700 | 3,500 | 3,500 | 4,000 | 3,750 |
| Male | 64 | 40-49 | | 2,700 | | | 2,700 |
| Male | 55 | 50-59 | | 2,400 | | | 2,400 |
| Male | 52 | 60-69 | 2,000 | 2,250 | | | 2,250 |
| Male | | 70+ | 2,200 | | | | 2,200 |
| Female | | 16-19 | 1,830 | | 3,070 | | 3,070 |
| Female | 55 | 20-39 | 2,000 | 2,200 | 2,600 | 3,000 | 3,000 |
| Female | 70 | 40-49 | 2,520 | 2,800 | 3,290 | | 2,800 |
| Female | 55 | 50-59 | | 1,980 | 2,150 | | 2,150 |
| Female | 52 | 60-69 | 1,947 | | | | 1,947 |
| Female | | 70+ | 1,850 | | | | 1,900 |

Jongman 2007: 599.

| Age | Male | Female |
|---|---|---|
| 0 | 757 | 700 |
| 5 | 1,323 | 1,226 |
| 10 | 1,984 | 1,762 |
| 15 | 2,700 | 2,400 |
| 20 | 2,903 | 2,285 |
| 25 | 2,683 | 2,083 |
| 30 | 2,683 | 2,083 |
| 35 | 2,600 | 2,117 |
| 40 | 2,600 | 2,117 |
| 45 | 2,600 | 2,117 |
| 50 | 2,600 | 2,117 |
| 55 | 2,600 | 2,117 |
| 60 | 2,600 | 2,117 |
| 65 | 2,200 | 1,883 |
| 70 | 2,200 | 1,883 |

**Author Legend**

- Fisher and Bender 1979: 27
- FAO/Denning 1979: 125, Table 3
- Foxhall and Forbes 1982: 49
- Gallant 1991: 73, Table 4.5
- Darby 1977: 54.
- Author's estimate

**Report 3.2b: Calorie requirements for manual and sedentary lifestyles**

| Demographic age bands | Manual lifestyles | | Sedentary lifestyles | |
|---|---|---|---|---|
| | Calorie requirement kcals/day | | Calorie requirement kcals/day | |
| | Male | Female | Male | Female |
| Children weaned in the second year | - | - | - | - |
| Children 3 years old | 1,000 | 1,000 | 1,000 | 1,000 |
| Children under 4- 6 years old | 1,878 | 1,790 | 1,455 | 1,333 |
| Children under 7-9 years old | 2,190 | 2,110 | 1,852 | 1,655 |
| Adolescents 10-12 years old | 2,600 | 2,600 | 2,127 | 1,890 |
| Adolescents 13-15 years old | 3,237 | 3,037 | 2,557 | 2,272 |

| Demographic age bands | Manual lifestyles | | Sedentary lifestyles | |
|---|---|---|---|---|
| | Calorie requirement kcals/day | | Calorie requirement kcals/day | |
| | Male | Female | Male | Female |
| 16-19 | 3,425 | 3,070 | 2,802 | 2,343 |
| 20-39 | 3,750 | 3,000 | 2,683 | 2,083 |
| 40-49 | 2,700 | 2,800 | 2,600 | 2,117 |
| 50-59 | 2,400 | 2,150 | 2,600 | 2,117 |
| 60-69 | 2,250 | 1,947 | 2,200 | 2,117 |
| 70+ | 2,200 | 1,900 | 2,200 | 1,883 |

# Calorific values of food

Report 3.3

| A | B | |
|---|---|---|
| **Food Category** | **kcals/kg used in this thesis** | |
| Flour wheat | 3,341 | |
| Flour hulled barley (Foxhall and Forbes 1982: 86) | 3,100 | |
| Hard wheat (Foxhall and Forbes 1982: 85) | 3,320 | |
| Soft Wheat (Foxhall and Forbes 1982: 85) | 3,340 | |
| Barley (Foxhall and Forbes 1982: 85) | 3,320 | |
| Potatoes | 720 | |
| Honey | 3,072 | |
| Pulses broad beans | 808 | Average = 1,005 |
| Pulses lentils | 1,050 | |
| Pulses chick peas | 1,157 | |
| Figs | 2,150 | |
| Palm dates | 2,500 | |
| Olives | 1,056 | |
| Veg. Leeks | 213 | |
| Veg. Cabbage | 168 | |
| Veg. Onions | 360 | |
| Wine/beer | 744 | |
| Mutton roasted (Halstead 1996: 34) | 2,500 | |
| Raw Fish Tuna | 1,356 | |
| Duck roasted | 2,007 | |
| Eggs | 1,017 | |
| Milk* | 814 | |
| Goats cheese | 3,164 | |
| Olive oil and fats | 9,000 | |

| Food type Legend |
|---|
| Cereals |
| Other carbo-hydrates |
| Pulses, Fruit and vegetables |
| Wine/beer |
| Protein |
| Dairy products |
| Oils and fats |

| Regions | Cypriot | | | Egypt | | |
|---|---|---|---|---|---|---|
| **Food type** | **Consumption kgs/person/yr** | **Energy intake kcals/day** | **% calories intake by food type** | **Consumption kgs/person/yr** | **Energy intake kcals/day** | **% calories intake by food type** |
| **Carbohydrates** | 247 | 2118 | 61.6 | 351 | 2571 | 75.6 |
| **Pulses and Veg** | 155 | 450 | 13.1 | 195 | 543 | 16 |
| **Protein & Dairy** | 49 | 253 | 7.4 | 34 | 161 | 4.8 |
| **Oils and fats** | 25 | 616 | 17.9 | 5 | 123 | 3.6 |
| **Total** | **476** | **3437** | **100** | **585** | **3398** | **100** |

Report 3.4a: Analysis of the proportion of calories by food type for Crete in the 1950's A.D. and the authors estimate for LBA Ancient Egypt

Report 3.4e

| Food Category kg | Calorific value of food stuff kcals/kg | [1]Adapted from Allbaugh's study of Crete 1947-51 A.D. | | | [2]Author's estimate Ancient Egyptian diet | | |
|---|---|---|---|---|---|---|---|
| | | Consumption kgs/person/yr | Energy intake kcals/day | % calories intake by food type | Consumption kgs/person/yr | Energy intake kcals/day | % calories intake by food type |
| Cereals (Wheat) | 3,341 | 225 | 2,060 | | 260 | 2,380 | 70 |
| Potatoes | 720 | | 0 | 59.9 | N/A | 0 | |
| Honey 3 | 3,072 | 2 | 17 | 0.5 | 1 | 8 | 0.2 |
| Pulses (average) | 1,005 | 75 | 225 | | 110 | 303 | |
| Vegetables (average) | 247 | 30 | 20 | | 50 | 34 | |
| Olives | 1,056 | 30 | 87 | | | | |
| Figs/palm dates | 2,150 | 20 | 118 | | 35 | 206 | |
| Toms. and citrus fruits | 213 | | | 13.1 | | 0 | 16 |
| Wine/grapes/figs/palm dates | 744 | 20 | 41 | | 5 | 10 | 0.3 |
| Beer | 744 | | 0 | 1.2 | 85 | 173 | 5.1 |
| Mutton | 2,500 | 20 | 137 | | 5 | 34 | |
| Fish | 1,356 | 15 | 56 | | 15 | 56 | |
| Duck/goose | 2,007 | 5 | 27 | 6.4 | 10 | 55 | 4.3 |
| Dairy Milk | 814 | 7 | 16 | | 3 | 7 | |
| Cheese | 3,164 | 2 | 17 | 1 | 1 | 9 | 0.5 |
| Oils and fats | 9,000 | 25 | 616 | 17.9 | 5 | 123 | 3.6 |
| | **Food consumed** | **476** | | | **585** | | |
| | **Energy kcals/day** | | 3,437 | 100 | | 3,398 | 100.0 |
| | **Carbohydrates** | **247** | **2,118** | **62** | **351** | **2,571** | **76** |
| | **Pulses and Veg** | **155** | **450** | **13.1** | **195** | **543** | **16** |
| | **Protein & Dairy** | **49** | **253** | **7.4** | **34** | **161** | **4.8** |
| | **Oils and fats** | **25** | **616** | **17.9** | **5** | **123** | **3.6** |

| Food type Legend |
|---|
| Cereals |
| Other carbo-hydrates |
| Pulses, Fruit and vegetables |
| Wine/grapes/beer |
| Protein |
| Dairy products |
| Oils and fats |

[1] Adapted from Allbaugh 1953: 107, Table 9 to reflect Cypriot diet in antiquity.

[2] Author's estimate based on evidence from Murray 2000a: 505-536; 2000b: 609-655; Murray 2000c: 577-608, and Darby 1977: 54-58, 130-156,

[3] Allbaugh's 1947 ommited honey consumption. The 1948 honey consumption (5.4 kg) added to the 1947 analysis, which increases energy intake.

| | % calories intake by food type | |
|---|---|---|
| | **Egypt** | **Cyprus** |
| Cereals | **70.2** | **59.9** |
| Pulses | **8.9** | **6.5** |
| | **79.1** | **66.4** |
| | Total protein kg | |
| | Cypriot | Egypt |
| | **40** | **30** |
| | Total dairy kg | **4** |

**Report 3.4b: : Number of sheep and shepherds to meet the protein requirements to stay healthy**

| | | | |
|---|---|---|---|
| Weight of protein consumed per individual per year | 20 | kg/person/year | |
| Total weight of mutton consumed by 100000 people less children under 3 | 1,764,600 | kg/year | |
| Weight (kg) of usable Mutton per animal (Lyman 1979: 542, Report 4) | 18 | kg | |
| No. of sheep/goats required/100000 individuals/yr | 98,033 | | |
| Average size of family from table 2.21 | 6 | | |
| No. of sheep/gaoats/family | 6 | | 7 |
| Flock size (Koster 1977: 277) | 50 | | |
| No. of shepherds required assuming shepherd to flock ratioo of 1 man/flock | **1,961** | | |

**Report 3.4f: Fish rations at Dier el-Medina**

| | |
|---|---|
| Tot ration kg/m'th | 8.4 |
| Total ration kg/yr | 100.8 |
| Av. no. adults | 6 |
| Fish/adult kg/yr | 15 |
| **10.2 kg/month (Janssen 1997:46)** | |
| Total ration kg/yr | 131 |
| Av. no. adults | 6 |
| Fish/adult kg/yr | 19 |

**Report 3.4c: Milk production**

| | Data based on FAO 1994 | |
|---|---|---|
| Mean lactation period | 150 | days |
| Mean weaning period | 50 | days |
| Milking surplus for human consumtion | 100 | days |
| Mean milk production ewe | 0.4 | kg/day |
| Total production surplus potential of the ewes | 1,960,660 | kg |
| 100000 population less children 3 and under | 88,230 | |
| Population over 3 | 11,770 | |
| Dairy requirement/person/yr Cypriot | 9 | kg |
| Requirement for 100000 less children under 3 | 794,070 | kg |
| Surplus dairy for Cypriot | 1,166,590 | kg |
| Dairy requirement/person/yr Egypt | 4 | kg |
| Requirement for 100000 less children under 3 | 352,920 | kg |
| Surplus dairy for Egypt | 1,607,740 | kg |

**Report 3.4d: : Total weight of protein consumed/100,000/year**

| | Cypriot kg | Egypt kg |
|---|---|---|
| Annual weight | 40 | 30 |
| Tot wt of protein consumed by 100000 people less children under 3 | 3,396,800 | 2,547,600 |

**Report 3.4e: Asumed mutton, fish, and fowl consumed kg/person/yr**

| Egypt | Cyprus |
|---|---|
| 5 | 20 |
| 15 | 15 |
| 10 | 5 |
| **30** | **40** |

**Report 3.4g: Cretan diets 1947/8 re Allbaugh 1953: Tables 9 and A49.**

Veg, olives, toms prorated proportional to 128 family study

% calories consumed were carbohydrates 49.0

| Food Source | Calorific value of food stuff kcals/kg | Allbaugh's study 128 families 7 day average fall season kg/person/yr | Energy intake kcals/day | % calories intake by food type | Allbaugh's adjusted annual estimate, 1948 study 765, families kg/person/yr | Energy intake kcals/day | % calories intake by food type |
|---|---|---|---|---|---|---|---|
| Cereals (Wheat) | 3341 | 128 | | | 128 | | |
| Potatoes | 720 | 59 | 1288 | 46.8 | 38.6 | 1248 | 46.2 |
| Honey 3 | 3072 | 5 | 42 | 1.5 | 5.4 | 45 | 1.7 |
| Pulses (average) | 1005 | 19 | | 0 | 23.2 | | 0 |
| Vegetables (average) | 247 | 55 | | 0 | 36.7 | | 0 |
| Olives | 1056 | 100 | | 0 | 66.7 | | 0 |
| Figs/palm dates | 2150 | | | 0 | | | 0 |
| Toms. and citrus | 213 | 43 | 404 | 14.7 | 28.7 | 298 | 11 |
| Wine/grapes | 744 | 10 | | 0 | 38.6 | | 0 |
| Beer | 744 | | 20 | 0.7 | | 79 | 2.9 |
| Mutton | 2500 | 29 | | 0 | 27.7 | | 0 |
| Fish | 1356 | | | 0 | | | 0 |
| Duck/goose | 2007 | | 199 | 7.2 | | 190 | 7 |
| Dairy Milk | 814 | 17 | | 0 | 34.5 | | 0 |
| Cheese | 3164 | | 38 | 1.4 | | 77 | 2.9 |
| Oils and fats | 9000 | 31 | 764 | 27.7 | 30.9 | 762 | 28.3 |
| **TOTAL** | | **496** | **2,755** | **100** | **459.0** | **2,699** | **100** |

# Demographics

Report 3.6

| | | | | Report 3.6a: Friers model | | | | Report 3.6b: Coale-Demeny Model South level 3 Female | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| d(x) | l(x) | q(x) | L(x) | T(x) | C(x) % | e(x) | ∑C(x) x-x+n | d(x) | T(x) | e(x)=T(x)/l(x) | ∑C(x) x-x+n |
| 35,822 | 100,000 | 0.3582 | 76,716 | 2,110,733 | 3.63 | 21.107 | 3.63 | 26,433 | 2,500,000 | 25 | 3.31 |
| 15,210 | 64,178 | 0.237 | 216,573 | 2,034,017 | 10.26 | 31.693 | 13.89 | 22,263 | 2,417,181 | 32.857 | 12.62 |
| 12,193 | | | | | | | 16.7 | | | | 15.08 |
| 3,140 | 48,968 | 0.0641 | 236,990 | 1,817,444 | 11.23 | 37.115 | 25.12 | 3,799 | 2,184,380 | 42.577 | 22.46 |
| 2,954 | | | | | | | 27.24 | | | | 24.32 |
| 2,396 | | | | | | | 33.59 | | | | 29.92 |
| 2,210 | 45,828 | 0.0482 | 223,615 | 1,580,454 | 10.59 | 34.487 | 35.71 | 1,892 | 1,938,307 | 40.802 | 31.78 |
| 2,619 | | | | | | | 39.69 | | | | 35.33 |
| 3,233 | 43,618 | 0.0741 | 210,008 | 1,356,839 | 9.95 | 31.107 | 45.66 | 2,490 | 1,705,323 | 37.387 | 40.66 |
| 3,317 | | | | | | | 53 | | | | 47.33 |
| 3,338 | 40,385 | 0.0827 | 193,580 | 1,146,831 | 9.17 | 28.397 | 54.83 | 2,931 | 1,483,234 | 34.395 | 49 |
| 3,443 | 37,047 | 0.0929 | 176,628 | 953,251 | 8.37 | 25.731 | 63.2 | 2,935 | 1,274,653 | 31.714 | 56.76 |
| 3,549 | 33,604 | 0.1056 | 159,148 | 776,623 | 7.54 | 23.111 | 70.74 | 2,836 | 1,080,738 | 29.008 | 63.94 |
| 3,654 | 30,055 | 0.1216 | 141,140 | 617,475 | 6.69 | 20.545 | 77.43 | 2,759 | 901,260 | 26.183 | 70.56 |
| 3,738 | | | | | | | 82.08 | | | | 75.42 |
| 3,759 | 26,401 | 0.1424 | 122,608 | 476,335 | 5.81 | 18.042 | 83.24 | 2,588 | 735,778 | 23.239 | 76.64 |
| 3,865 | 22,642 | 0.1707 | 103,548 | 353,727 | 4.91 | 15.623 | 88.15 | 2,519 | 583,681 | 20.076 | 82.21 |
| 3,949 | | | | | | | 91.33 | | | | 86.23 |
| 3,970 | 18,777 | 0.2114 | 83,960 | 250,179 | 3.98 | 13.324 | 92.13 | 2,980 | 444,358 | 16.733 | 87.23 |
| 3,711 | 14,807 | 0.2506 | 64,758 | 166,219 | 3.07 | 11.226 | 95.2 | 3,572 | 318,735 | 13.52 | 91.6 |
| 3,652 | | | | | | | 96.96 | | | | 94.43 |
| 3,637 | 11,096 | 0.3278 | 46,388 | 101,461 | 2.2 | 9.144 | 97.4 | 4,810 | 209,433 | 10.47 | 95.14 |
| 3,082 | 7,459 | 0.4132 | 29,590 | 55,073 | 1.4 | 7.383 | 98.8 | 5,335 | 120,961 | 7.961 | 97.67 |
| 2,464 | | | | | | | 99.41 | | | | 98.86 |
| 2,310 | 4,377 | 0.5278 | 16,110 | 25,483 | 0.76 | 5.82 | 99.56 | 5,029 | 57,798 | 5.863 | 99.16 |
| 1,396 | 2,067 | 0.6754 | 6,845 | 9,373 | 0.32 | 4.53 | 99.88 | 3,319 | 20,576 | 4.261 | 99.79 |
| 671 | 671 | 1 | 2,528 | 2,528 | 0.12 | 3.77 | 100 | 1,193 | 4,727 | 3.13 | 99.95 |
| | | | | | | | 100 | 1 | 1 | 1.113 | 100 |
| | | Frier's life expectancy at birth = | | 21.1 | yrs | | | Coale-Demeny's life expectancy at birth = | | 25 | yrs |

| | |
|---|---|
| | Interpolated |

Where x = The exact age. By convention these Tables are index origin zero.
d(x) = Mortality between this age and the next. For example d1 means 15210 had died between the first and second year.
l(x) = Number of survivors for age x. By convention 'cohort' l0 is taken as 100,000
q(x) = Probability of dying between this age and the next age = d(x)/l(x)
L(x) = The number of person-years lived between x and x+n. For example at exact age 25 years L25 = 5 * (37047+33604)/2 = 176628
T(x) = Total number of person years lived after x. For example T60 = 46388+29590+16110+6845+2528 = 101461 years.
C(x) = Proportion of the total population that each group represents. For example C20 = 100 * L20/T0 = 100* 193580/2110733= 9.17%.
e(x) = Average life expectancy = Tx/lx. This means average life expectancy at birth is e0 = To/l0 = 2110733/100000 = 21.107 years.

**Report 3.7: Estimated demographic age profile in antiquity using results from Report 5**

**Report 3.7a**

**Frier's life expectancy**

| Age bands | % survivors | Accum % survivors | No. of survivors |
|---|---|---|---|
| 0-1 | 3.63 | 3.63 | 3,630 |
| 2 to 3 | 13.07 | 16.7 | 13,070 |
| 4 to 6 | 10.54 | 27.24 | 10,540 |
| 7 to 9 | 6.35 | 33.59 | 6,350 |
| 10 to 12 | 6.1 | 39.69 | 6,100 |
| 13 to 15 | 5.97 | 45.66 | 5,970 |
| 16 to 19 | 7.34 | 53 | 7,340 |
| 20 to 39 | 29.08 | 82.08 | 29,080 |
| 40 to 49 | 9.25 | 91.33 | 9,250 |
| 50 to 59 | 5.63 | 96.96 | 5,630 |
| 60 to 69 | 2.45 | 99.41 | 2,450 |
| 70+ | 0.59 | 100 | 590 |
| | **100** | | **100,000** |

**Coale-demeny Model South Level 3 Female**

| Age bands | % survivors | Accum % survivors | No. of survivors |
|---|---|---|---|
| 0-1 | 3.31 | 3.31 | 3,310 |
| 2 to 3 | 11.77 | 15.08 | 11,770 |
| 4 to 6 | 9.24 | 24.32 | 9,240 |
| 7 to 9 | 5.6 | 29.92 | 5,600 |
| 10 to 12 | 5.41 | 35.33 | 5,410 |
| 13 to 15 | 5.33 | 40.66 | 5,330 |
| 16 to 19 | 6.67 | 47.33 | 6,670 |
| 20 to 39 | 28.09 | 75.42 | 28,090 |
| 40 to 49 | 10.81 | 86.23 | 10,810 |
| 50 to 59 | 8.2 | 94.43 | 8,200 |
| 60 to 69 | 4.43 | 98.86 | 4,430 |
| 70+ | 1.14 | 100 | 1,140 |

**Report 3.7b**

| Demographic age group. | Accum % survivors | From Report 3.21 family size equal to 6 | From Report 3.8 kcals/yr av. of male+female | Accum % survivors |
|---|---|---|---|---|
| Children under 3 years old | 15.08 | 0.9 | 1,288,815 | 15.1 |
| Children under 4-9 years old | 14.84 | 0.89 | 1,205,194 | 14.8 |
| Adolescents 10-15 years old | 10.74 | 0.64 | 1,799,402,696 | 10.7 |
| Adults 16-50 years old | 45.57 | 2.73 | 1,075,473 | 45.6 |
| Elderly over 50 years old | 13.77 | 0.83 | 1,393,233 | 13.8 |
| Total | 100 | 5.99 | **1,804,365,411** | 100 |
| Family size = | 6 | | | |

**Report 3.7c**

**Enter 1 for Frier's model or 2 for Coale-Demeny model** **2**

| | |
|---|---|
| Children under 3 years old | **16.7** |
| Children under 4-9 years old | **16.89** |
| Adolescents 10-15 years old | **12.07** |
| Adults 16-50 years old | **45.67** |
| Elderly over 50 years old | **8.67** |
| **Total** | **100** |

| | |
|---|---|
| Populaion excluding children under 3 = | 83.3 |
| No of people over 3 in 100,000 sample= | 83300 |
| | % |
| Percentage population socio-economic groups 1-3 | 3.8 |
| Percentage population socio-economic groups 4-5 | 96.2 |
| | 100 |

**Unproductive individuals**

| | | | |
|---|---|---|---|
| Children aged 5 and under | 15,080 | Total elite SEG 1-3 | 3800 |
| Elderly over 60 years old | 5,570 | Adults 5-60 | 3015 |
| Total | **20650** | | |
| Elite adults | | | |

**Report 3.7d**

| Demographic age bands | Coale-Demeny Survivors | Frier's model Survivors |
|---|---|---|
| Children under 3 years old | 15,080 | 16,700 |
| Children under 4-9 years old | 14,840 | 16,890 |
| Adolescents 10-15 years old | 10,740 | 12,070 |
| Adults 16-50 years old | 45,570 | 45,670 |
| Adults 50-60 years old | 8,200 | 5,630 |
| Elderly 60+ | 5,570 | 3,040 |
| **Total** | 100,000 | 100,000 |

**Report 3.7e**

| Age span | Accum % survivors | No. of survivors |
|---|---|---|
| 0-6 | 22.46 | 22,460 |
| 55+ | 8.4 | 8,400 |
| | | 30,860 |

| | |
|---|---|
| Proportion under 3 and over 60 | 0.2065 |
| Percentage under 3 and over 60 | 21 |
| Male population 10-60 | 32255 |
| Percentage of the population over 40 | 24.58 |
| Percentage of the population over 50 | 13.77 |
| No. of craftsmen 16-50 | 501,600 |

**Report 3.7f**

| Kemp 2008: 44. | **Number of workers exhumed at Amarna** | |
|---|---|---|
| 0 to 5 | 9 | 13.2 |
| 6 to 20 | 35 | 51.5 |
| 21-35 | 14 | 20.6 |
| 36-50 | 8 | 11.8 |
| 50+ | 2 | 2.9 |
| | **68** | **100** |

# Total calorie requirement

| Report 3.8: Total energy requirements | | Report 3.8a | | | | | Report 3.8b | | | Report 3.8c | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Total energy requirements of 100000 people by demographic age group | | | | Sedentary population | | | Frier's model | | |
| Sex | Age Range | Energy expended used in thesis kcals/day | 1 Demographic age profile that require feeding from | Total kcals required per day per 100,000 people | Total Million kcals required per annum per 100,000 | Energy expended used in thesis kcals/day | Total kcals required per day per 100,000 people | Total Million kcals required per annum per 100,000 | Frier's Demographic age profile that require | Total kcals required per day per 100,000 people | Total Million kcals required per annum per 100,000 |
| Child male and female 1 | 0 to 1 | - | 3,310 | - | - | - | - | - | 3,630 | - | - |
| Child male and female 1 | 2 to 3 | 1,000 | 11,770 | 11,770,000 | 4,296 | 1,000 | 11,770,000 | 4,296 | 13,070 | 13,070,000 | 4,771 |
| Child male | 4 to 6 | 1,878 | 4,620 | 8,676,360 | 3,167 | 1,455 | 6,722,100 | 2,454 | 5,270 | 9,897,060 | 3,612 |
| Child female | 4 to 6 | 1,790 | 4,620 | 8,269,800 | 3,018 | 1,333 | 6,158,460 | 2,248 | 5,270 | 9,433,300 | 3,443 |
| Child male | 7 to 9 | 2,190 | 2,800 | 6,132,000 | 2,238 | 1,852 | 5,185,040 | 1,893 | 3,175 | 6,953,250 | 2,538 |
| Child female | 7 to 9 | 2,110 | 2,800 | 5,908,000 | 2,156 | 1,655 | 4,633,440 | 1,691 | 3,175 | 6,699,250 | 2,445 |
| Male Adolescent | 10 to 12 | 2,600 | 2,705 | 7,033,000 | 2,567 | 2,127 | 5,754,076 | 2,100 | 3,050 | 7,930,000 | 2,894 |
| Male Adolescent | 13-15 | 3,237 | 2,705 | 8,756,085 | 3,196 | 2,557 | 6,916,144 | 2,524 | 3,050 | 9,872,850 | 3,604 |
| Female Adolescent | 10 to 12 | 2,600 | 2,665 | 6,929,000 | 2,529 | 1,890 | 5,035,784 | 1,838 | 2,985 | 7,761,000 | 2,833 |
| Female Adolescent | 13-15 | 3,037 | 2,665 | 8,093,605 | 2,954 | 2,272 | 6,055,946 | 2,210 | 2,985 | 9,065,445 | 3,309 |
| Male | 16-19 | 3,425 | 3,335 | 11,422,375 | 4,169 | 2,802 | 9,343,002 | 3,410 | 3,670 | 12,569,750 | 4,588 |
| Male | 20-39 | 3,750 | 14,045 | 52,668,750 | 19,224 | 2,683 | 37,682,735 | 13,754 | 14,540 | 54,525,000 | 19,902 |
| Male | 40-49 | 2,700 | 5,405 | 14,593,500 | 5,327 | 2,600 | 14,053,000 | 5,129 | 4,625 | 12,487,500 | 4,558 |
| Male | 50-59 | 2,400 | 4,100 | 9,840,000 | 3,592 | 2,600 | 10,660,000 | 3,891 | 2,815 | 6,756,000 | 2,466 |
| Male | 60-69 | 2,250 | 2,215 | 4,983,750 | 1,819 | 2,200 | 4,873,000 | 1,779 | 1,225 | 2,756,250 | 1,006 |
| Male | 70+ | 2,200 | 570 | 1,254,000 | 458 | 2,200 | 1,254,000 | 458 | 295 | 649,000 | 237 |
| Female | 16-19 | 3,070 | 3,335 | 10,238,450 | 3,737 | 2,343 | 7,812,237 | 2,851 | 3,670 | 11,266,900 | 4,112 |
| Female | 20-39 | 3,000 | 14,045 | 42,135,000 | 15,379 | 2,083 | 29,255,735 | 10,678 | 14,540 | 43,620,000 | 15,921 |
| Female | 40-49 | 2,800 | 5,405 | 15,134,000 | 5,524 | 2,117 | 11,442,385 | 4,176 | 4,625 | 12,950,000 | 4,727 |
| Female | 50-59 | 2,150 | 4,100 | 8,815,000 | 3,217 | 2,117 | 8,679,700 | 3,168 | 2,815 | 6,052,250 | 2,209 |
| Female | 60-69 | 1,947 | 2,215 | 4,312,605 | 1,574 | 2,117 | 4,689,155 | 1,712 | 1,225 | 2,385,075 | 871 |
| Female | 70+ | 1,900 | 570 | 1,083,000 | 395 | 1,883 | 1,073,310 | 392 | 295 | 560,500 | 205 |
| | | | 100,000 | 248,048,280 | 90,536 | | 199,049,250 | 72,652 | 100,000 | 247,260,380 | 90,251 |

| Data source legend | |
|---|---|
| Fisher and Bender 1979: 27 | |
| Denning 1979: 125, Table 3 | |
| Foxhall and Forbes 1982: 49 | |
| Gallant 1991: 73, Table 4.5 | |
| Author's interpolated data | |

[1] Assumption is infants years 1-2 are breast fed, therefore for infants aged 1-3 only one third require feeding from land produce

**Report 3.8d: Total calories required for active + sedentary required Million kcals /yr/100000 people**

| Physical versus sedentary lifestyles | Total Million kcals required/yr/100000 people | |
|---|---|---|
| | Percentage split | Energy |
| Population with high physical labour lifestyl | 75 | 67,902 |
| Population with sedentary lifestyles | 25 | 18,163 |
| **Total energy required** | **100** | **86,065** |

**Report 3.8e: Total calories required for active + sedentary required Million kcals /yr/100000 people**

| Demographic age band | Total Million kcals required/yr/100000 people | |
|---|---|---|
| | Active | Sedentary |
| Children under 3 years old | 3,222 | 1,074 |
| Children under 4-9 years old | 7,934 | 2,072 |
| Adolescents 10-15 years old | 8,435 | 2,168 |
| Adults 16-50 years old | 40,020 | 10,000 |
| Elderly over 50 years old | 8,291 | 2,850 |
| **Totals** | **67,902** | **18,163** |
| **Totals of active and sedentary** | **86,065** | |

**Report 3.8f: Summary of Coale-Demeny and Friers calorie requirement assuming no sedentary workers**

| Demographic age band | Total Million kcals required/yr/100000 people | |
|---|---|---|
| | Coale-Demeny | Frier's |
| Children under 3 years old | 4,296 | 4,771 |
| Children under 4-9 years old | 10,579 | 12,038 |
| Adolescents 10-15 years old | 11,246 | 12,640 |
| Adults 16-50 years old | 53,360 | 53,808 |
| Elderly over 50 years old | 11,055 | 6,994 |
| **Total** | **90,536** | **90,251** |

| | |
|---|---|
| **% difference between Frier and Coale-Demeny's** | **0.3** |

## Report 3.9: Total calorie requirement for 100000 people by geographic region and by food type eaten in antiquity

### Report 3.9a: Rain dependent regions(e.g. Cyprus) based on Allbaugh's 1953 Cretan ethnographic study

| Food type | % split by food type of the 1947/48 Cretan diet analysed by Allbaugh | Allbaugh study adjusted assuming lower olive oil content in antiquity | Energy in Million kcals required/yr/ 100000 people | % of the calories provided by cereals, potatoes, honey, and alcohol |
|---|---|---|---|---|
| Cereals | 46.2 | 59.9 | 51553 | 50.8 |
| Other carbs. | 1.7 | 0.5 | 430 | |
| Pulses and veg. | 11 | 13.1 | 11275 | |
| Wine | 2.9 | 1.2 | 1033 | |
| Protein | 7 | 6.4 | 5508 | |
| Dairy | 2.9 | 1 | 861 | |
| Oils and fats | 28.3 | 17.9 | 15405 | |
| Total | 100 | 100 | 86,065 | |

* In antiquity 'other carbohydrates' would be cereals.

** Beer is assumed made from barley and therefore allocated to barley (see Darby 1976: 537).

### Report 3.9c: Egypt

| | | | | |
|---|---|---|---|---|
| Cereals | 70 | 60246 | | |
| Other carbs* | 0.2 | 172 | | |
| Pulses and veg. | 16 | 13770 | | |
| Beer** | 5.1 | 4389 | % proportion of the calories of barley for beer to total barley | 9 |
| Wine | 0.3 | 258 | | |
| Protein | 4.3 | 3701 | | |
| Dairy | 0.5 | 430 | | |
| Oils and fats | 3.6 | 3099 | | |
| Total | 100 | 86,065 | | |

| Food type Legend |
|---|
| Cereals |
| Other carbo-hydrates |
| Wine/beer |
| Pulses, Fruit and vegetables |
| Protein |
| Dairy products |
| Oils and fats |

### Report 3.9b: Data used for Cyprus based on Allbaugh's Cretan study

| Adapted figures of Allbaugh's 1953 study used for this thesis. Food type 'other carbohydrates' allocated to cereals | % split by food type | Energy in Million kcals required/yr/ 100000 people |
|---|---|---|
| Barley | 27.2 | 23,392 |
| Emmer Wheat | 33.2 | 28,591 |
| Pulses and vegetables | 13.1 | 11,275 |
| Wine | 1.2 | 1,033 |
| Protein -mutton/fish/duck | 6.4 | 5,508 |
| Dairy | 1 | 861 |
| Oils and fats | 18 | 15,405 |
| Total | 100 | 86,065 |
| Total cereal energy | 60.4 | 51,983 |

### Report 3.9d: Egypt

| | | |
|---|---|---|
| Barley | 56.5 | 48,605 |
| Emmer Wheat | 18.8 | 16,202 |
| Pulses and vegetables | 16 | 13,770 |
| | | |
| Wine | 0.3 | 258 |
| Protein -mutton/fish/duck | 4.3 | 3,701 |
| Dairy | 0.5 | 430 |
| Oils and fats | 3.6 | 3,099 |
| Total | 100 | 86,065 |
| Total cereal energy | 75.3 | 64,807 |

### Report 3.9e

% split of barley and emmer wheat grown

| | Barley | Emmer wheat | Total % |
|---|---|---|---|
| Cypriot | 45 | 55 | 100 |
| Egypt | 75 | 25 | 100 |

### Report 3.9f

% contribution of cereals calories to the diet

| | Barley | Emmer wheat | Total |
|---|---|---|---|
| Cypriot | 27.2 | 33.2 | 60.4 |
| Egypt | 56.5 | 18.8 | 75.3 |

% split of cereals grown into barley and emmer wheat

| | Barley | Emmer wheat | Total % |
|---|---|---|---|
| Cypriot | 45 | 55 | 100 |
| Egypt | 75 | 25 | 100 |

### Report 3.9g

| | |
|---|---|
| Cereal calories million kcal /yr | 64,807 |
| Family size less breast fed baby | 6 |
| Less one child breastfed | 5 |
| Cereal calories million kcal /yr | 12,961 |
| Source Kemp 1991: 157. | |

| Region | Cyprus | | Egypt | |
|---|---|---|---|---|
| Food type | % | Million kcal /yr | % | Million kcal /yr |
| Barley | 27.2 | 23,392 | 56.5 | 48,605 |
| Emmer wheat | 33.2 | 28,591 | 18.8 | 16,202 |
| Pulses and veg. | 13.1 | 11,275 | 16 | 13,770 |
| Wine/grape juice | 1.2 | 1,033 | 0.3 | 258 |
| Meat protein | 6.4 | 5,508 | 4.3 | 3,701 |
| Dairy products | 1 | 861 | 0.5 | 430 |
| Oils and fats | 18 | 15,405 | 3.6 | 3,099 |
| Total | 100 | 86,065 | 100 | 86,065 |

# Crop yields

**Report 3.10: Example of the yield (kg/ha) for cereals and pulses from the Cypriot using traditional farming practices**

| Reference | Area | Barley kg/ha | Wheat kg/ha | Broad beans kg/ha | Lentils kg/ha | Total pulses beans + lentils |
|---|---|---|---|---|---|---|
| 1 Gallant 1991: 77, Table 4.7 | Achaia | 695.5 | 642.7 | 743.5 | 594.5 | |
| 1 Gallant 1991: 77, Table 4.7 | Aitolia | 666.9 | 666.4 | 650.9 | 537.2 | |
| 1 Gallant 1991: 77, Table 4.7 | Argolid | 733.4 | 624.5 | 542.7 | 498.1 | |
| 1 Gallant 1991: 77, Table 4.7 | Arkadia | 598.7 | 470 | 657.2 | 410.9 | |
| 1 Gallant 1991: 77, Table 4.7 | Athens | 793.7 | 629.1 | 630.9 | 539.9 | |
| 1 Gallant 1991: 77, Table 4.7 | Evros | 990.3 | 871.9 | 638.4 | 611.2 | |
| 1 Gallant 1991: 77, Table 4.7 | Evvoia | 552.7 | 540 | 602.7 | 444.5 | |
| 1 Gallant 1991: 77, Table 4.7 | Crete | 902.6 | 748.1 | 624.7 | 578.8 | |
| 1 Gallant 1991: 77, Table 4.7 | Epiros | 563.6 | 536.4 | 478.7 | 589.1 | |
| 1 Gallant 1991: 77, Table 4.7 | Kalamata | 650.9 | 571.8 | 659.1 | 482.7 | |
| 1 Gallant 1991: 77, Table 4.7 | Kavala | 907 | 903.2 | 976 | 608.1 | |
| 1 Gallant 1991: 77, Table 4.7 | Kefalonia | 698.1 | 754.8 | 876.4 | 718.8 | |
| 1 Gallant 1991: 77, Table 4.7 | Kerkyra | 529.1 | 581 | 521.9 | 547.7 | |
| 1 Gallant 1991: 77, Table 4.7 | Korinth | 708.8 | 611 | 537.2 | 484.6 | |
| 1 Gallant 1991: 77, Table 4.7 | Kozani | 899 | 720 | 691.4 | 449.4 | |
| 1 Gallant 1991: 77, Table 4.7 | Lakonia | 627.7 | 646.4 | 621.8 | 453.6 | |
| 1 Gallant 1991: 77, Table 4.7 | Lesbos | 689.2 | 662.6 | 539.6 | 465.1 | |
| 1 Gallant 1991: 77, Table 4.7 | Phthiotis | 650 | 668.2 | 460.9 | 370 | |
| 1 Gallant 1991: 77, Table 4.7 | Thessaly | 1097.1 | 889.5 | 886.9 | 504 | |
| 1 Gallant 1991: 77, Table 4.7 | Zakynthos | 689.1 | 733.6 | 1098.2 | 924.6 | |
| Tsouderos 1919: 132 | Mainland Greece | | 742 | | | |
| 2 Gomme 1933: 31 | Attica-Boeotia | 650 | 350 | | | |
| 2 Gomme 1933: 31 | Attica-Boeotia | 660 | 290 | | | |
| 2 Gomme 1933: 31 | Laconia | 590 | 560 | | | |
| 2 Gomme 1933: 31 | Laconia | 700 | 770 | | | |
| 2 Gomme 1933: 31 | Messenia | 690 | 710 | | | |
| 2 Gomme 1933: 31 | Messenia | 770 | 730 | | | |
| 2 Gomme 1933: 31 | Larissa | 640 | 400 | | | |
| 2 Gomme 1933: 31 | Larissa | 520 | 400 | | | |
| 2 Gomme 1933: 31 | Trikkala | 270 | 350 | | | |
| 2 Gomme 1933: 31 | Trikkala | 610 | 560 | | | |
| **AVERAGE** | | 732 | 677 | 672 | 541 | 499 |
| **± 95% CONFIDENCE LEVEL** | | 67 | 50 | 74 | 53 | 52 |
| Average - 95% confidence level | | 665 | 627 | 598 | 488 | 447 |
| Average + 95% confidence level | | 799 | 727 | 746 | 594 | 551 |
| **MAXIMUM** | | 1097 | 903 | 1098 | 925 | 1098 |
| **MINIMUM** | | 529 | 470 | 461 | 370 | 108 |
| **STANDARD DEVIATION** | | 153 | 116 | 168 | 122 | 162 |
| **AVERAGE DEVIATION** | | 120 | 90 | 124 | 85 | 117 |

1 Greek data source National Statistical Service of Greece directed by P. Garnsey funded by the Economic and Social Research Council, collated by Gallant 1991: 77, Table 4.7.

2 Greek data supplied to A.W. Gomme by the Greek Legation in London for the years 1922-1923 respectively.

**Report 3.11a: Egyptian cereal yields (textual, ethnographic and government records)**

| Reference | Ref | Period | Barley kg/ha |
|---|---|---|---|
| James and Gunn 1962: 115. | Hekenakhte P. | Middle Kingdom | 750 |
| James and Gunn 1962: 115. | Hekenakhte P. | Middle Kingdom | 1250 |
| Gardiner 1941: 64-66; 1948: 198. | Wilbour P. | ca. 1150 B.C. | 1067 |
| Gardiner 1948: 198. | Wilbour P. | ca. 1150 B.C. | 534 |
| Rathbone 1991: 242-243. | Middle Egypt | 3rd c. A.D. | 1242 |
| Rathbone 1991: 242-243. | Middle Egypt | 3rd c. A.D. | 877 |
| Rathbone 1991: 242-243. | Theadelphia | 3rd c. A.D. | 1728 |
| **AVERAGE** | | | 1064 |
| **95% CONFIDENCE LEVEL ±** | | | 290 |
| **Average - 95% confidence level** | | | 774 |
| **Average + 95% confidence level** | | | 1354 |
| **MAXIMUM** | | | 1728 |
| **MINIMUM** | | | 534 |
| **STANDARD DEVIATION** | | | 392 |
| **AVERAGE DEVIATION** | | | **295** |

**Report 3.11c**

| Crop yield | Kgs of nitrogen fertilizer applied in 1937 | | | | |
|---|---|---|---|---|---|
| **ardebs/feddan** | **0** | **100** | **150** | **200** | **300** |
| **Barley** | 7.5 | 10.6 | 11.6 | 12.6 | 13.3 |
| **Barley ratio** | | 0.71 | 0.64 | 0.6 | 0.56 |
| **Wheat** | 4.9 | 6.8 | 7.4 | 7.8 | 9.3 |
| **Wheat ratio** | | 0.72 | 0.67 | 0.63 | 0.53 |

| | | |
|---|---|---|
| Reduction in yield of barley pre-fertilisers | 36 | 0.64 |
| Reduction in yield of wheat pre-fertilisers | 33 | 0.67 |

**Report 3.11b: Levantine cereal yields (textual, ethnographic and government records)**

| Reference | Area | Barley kg/ha | Wheat kg/ha |
|---|---|---|---|
| Simms and Russell 1997: Table 1 | Petra L. Wadi Beida | | 900 |
| Simms and Russell 1997: Table 1 | Petra L. Wadi Beida | | 1,580 |
| Simms and Russell 1997: Table 1 | Petra L. Wadi Beida | | 660 |
| Simms and Russell 1997: Table 1 | Petra L. Wadi Beida | | 400 |
| Simms and Russell 1997: Table 1 | Petra L. Wadi Beida | | 330 |
| Simms and Russell 1997: Table 1 | Petra L. Wadi Beida | | 2,480 |
| Simms and Russell 1997: Table 1 | S. Petra Valley | | 950 |
| Simms and Russell 1997: Table 1 | S. Petra Valley | | 640 |
| Adams 1928: Table 13 | Palestine 1926 | | 720 |
| Steitieh and Smadi 1974: 13, Table 2 | Jordan East Bank | | 690 |
| Steitieh and Smadi 1974: 10, Table 1 | Tot. Jordan 1957-66 | | 520 |
| Zohary 1969: 56 | Eastern Galilee | | 1,000 |
| Gallant 1991: 48 citing Worcello 1969 | Lebanon | | 1,460 |
| Gallant 1991: 48 citing Worcello 1969 | Lebanon | | 1,520 |
| Gallant 1991: 48 citing Worcello 1969 | Lebanon | | 1,560 |
| Mayerson 1955: 55; 1960: 18 | Negeb | 600 | 500 |
| Simpson 1930: 185, Appendix 24 | Mandate Palestine | 480 | 630 |
| Simpson 1930: 177 | Israel | 600 | 500 |
| Avitsur 1972: 214 | Iretze (Israel) | 600 | 550 |
| Weitz 1950: 35 | Negeb | 250 | 275 |
| Weitz 1950: 35 | Negeb | 1,670 | 1,630 |
| Weitz 1950: 35 | Negeb | 80 | 870 |
| Webley 1972: 173, 175 | Tell Gezer, Israel | 595 | |
| Helms 1981: 187 | Northern Jordon | 500 | |
| Simms and Russell 1997: Table 1 | Ras Mu'aesrah | 720 | |
| Simms and Russell 1997: Table 1 | Ras Mu'aesrah | 600 | |
| Simms and Russell 1997: Table 1 | S. Petra Valley | 440 | |
| Simms and Russell 1997: Table 1 | S. Petra Valley | 1,350 | |
| Simms and Russell 1997: Table 1 | S. Petra Valley | 670 | |
| Simms and Russell 1997: Table 1 | S. Petra Valley | 500 | |
| | **AVERAGE** | 644 | 926 |
| | **95% CONFIDENCE LEVEL ±** | 198 | 231 |
| | **Average - 95% confidence level** | 446 | 695 |
| | **Average + 95% confidence level** | 842 | 1,157 |
| | **MAXIMUM** | 1,670 | 2,480 |
| | **MINIMUM** | 80 | 275 |
| | **STANDARD DEVIATION** | 392 | 554 |
| | **AVERAGE DEVIATION** | 245 | 434 |

**Excluding maximum and minimun outliers**

| | | |
|---|---|---|
| **AVERAGE** | 633 | 881 |
| **95% CONFIDENCE LEVEL ±** | 181 | 190 |
| **Average - 95% confidence level** | 452 | 691 |
| **Average + 95% confidence level** | 814 | 1071 |
| **MAXIMUM** | 1670 | 1630 |
| **MINIMUM** | 250 | 330 |
| **STANDARD DEVIATION** | 333 | 434 |
| **AVERAGE DEVIATION** | 179 | 356 |

| Report 3.12: Yield rates for Egypt and Iraq representative of irrigated flood plain agriculture | | | | | | Enter 0 for data refelecting application of fertizers and 1 for no application | | | | 1 |
|---|---|---|---|---|---|---|---|---|---|---|
| Reference | Year | Barley yield | | Wheat yield | | Horse Beans | Horse Beans | Barley yield | Wheat yield | Enter 1 for fertilizer rate of 100 kg/feddan, 1.5 for 150, 2 for 200 and 3 for 300 |
| | | ardeb/feddan | kg/ha | ardeb/feddan | kg/ha | ardeb/feddan | kg/ha | kg/ha | kg/ha | |
| James and Gunn 1962: 115 re Hekenakhte P. | Middle Kingdom | - | 750 | - | | - | - | 750 | - | |
| James and Gunn 1962: 115 re Hekenakhte P. | Middle Kingdom | - | 1,250 | - | | - | - | 1,250 | - | |
| Gardiner 1941: 64-66; 1948: 198 re Wilbour P.. | ca. 1150 B.C. | - | 1,067 | - | | - | - | 1,067 | - | |
| Gardiner 1948: 198 re Wilbour P. | ca. 1150 B.C. | - | 534 | - | | - | - | 534 | - | |
| Rathbone 1991: 242-243 re Middle Egypt | 3rd c. A.D. | - | 1,242 | - | | - | - | 1,242 | - | |
| Rathbone 1991: 242-243 re Middle Egypt | 3rd c. A.D. | - | 877 | - | | - | - | 877 | - | |
| Hopkins 1983: 91 data 1925-34 | | - | - | - | 1,710 | - | - | - | 1,146 | |
| Willcocks 1889: 255-256 (IYAS 1922-1938). | Late 19th c. A.D. | - | 2,089 | - | 1,828 | - | - | 1,337 | 1,225 | |
| Ross 1889: X. | Late 19th c. A.D. | - | 2,055 | - | 1,631 | - | - | 1,315 | 1,093 | |
| Allbaugh 1953: 267, Table 48 | 1934-1938 | - | 1,622 | - | | - | - | 1,038 | | |
| Scheidel 2001: 224 citing with full references the 19th c. A.D. yields given in O'Brien 1968, Owen 1969, Rivlin 1961. | 1844 | 3.557 | 1,016 | 2.772 | 990 | 2.673 | 986 | 1016 | 990 | Pre-application of chemical fertilisers |
| | 1844 | 4 | 1,143 | 3 | 1,071 | 3 | 1107 | 1143 | 1,071 | |
| | 1872 | 2.02 | 577 | 2.21 | 789 | 1.84 | 679 | 577 | 789 | |
| | 1881/1885 | 2.21 | 631 | 3.364 | 1,201 | 2.256 | 833 | 631 | 1,201 | |
| | 1886/1890 | 3.33 | 951 | 3.818 | 1,364 | 2.656 | 980 | 951 | 1,364 | |
| 1 Adams 1965: 17. | 1958 | - | 1,396 | - | 1,132 | - | - | 893 | 758 | |
| 2 Adams 1965: 17. | 1958 | - | 1,025 | - | 764 | - | - | 656 | 512 | |
| Richards 1982: Table 5.2, 145 | 1920 | 5.78 | 1,651 | 5.02 | 1,793 | 4.46 | 1,646 | 1,057 | 1,201 | |
| Richards 1982: Table 5.2, 145 | 1921 | 5.71 | 1,631 | 4.78 | 1,707 | 4.46 | 1,646 | 1,044 | 1,144 | |
| Richards 1982: Table 5.2, 145 | 1922 | 5.68 | 1,623 | 4.55 | 1,625 | 4.44 | 1,639 | 1,039 | 1,089 | |
| Richards 1982: Table 5.2, 145 | 1923 | 5.64 | 1,611 | 4.98 | 1,779 | 4.43 | 1,635 | 1,031 | 1,192 | |
| Richards 1982: Table 5.2, 145 | 1924 | 5.44 | 1,554 | 4.55 | 1,625 | 3.95 | 1,458 | 995 | 1,089 | |
| Richards 1982: Table 5.2, 145 | 1925 | 5.72 | 1,634 | 4.94 | 1,764 | 4.45 | 1,642 | 1,046 | 1,182 | |
| Richards 1982: Table 5.2, 145 | 1926 | 5.71 | 1,631 | 4.57 | 1,632 | 3.87 | 1,428 | 1,044 | 1,093 | |
| Richards 1982: Table 5.2, 145 | 1927 | 6 | 1,714 | 5.05 | 1,804 | 4.65 | 1,716 | 1,097 | 1,209 | |
| Richards 1982: Table 5.2, 145 | 1928 | 5.55 | 1,586 | 4.42 | 1,579 | 3.8 | 1,402 | 1,015 | 1,058 | |
| Richards 1982: Table 5.2, 145 | 1929 | 5.95 | 1,700 | 5.28 | 1,886 | 4.56 | 1,683 | 1,088 | 1,264 | |
| Richards 1982: Table 5.2, 145 | 1930 | 5.74 | 1,640 | 4.92 | 1,757 | 4.31 | 1,591 | 1,050 | 1,177 | |
| Richards 1982: Table 5.2, 145 | 1931 | 5.97 | 1,706 | 5.26 | 1,879 | 4.17 | 1,539 | 1,092 | 1,259 | |
| Richards 1982: Table 5.2, 145 | 1932 | 6.21 | 1,774 | 5.62 | 2,007 | 4.87 | 1,797 | 1,135 | 1,345 | |
| Richards 1982: Table 5.2, 145 | 1933 | 5.95 | 1,700 | 5.28 | 1,886 | 4.47 | 1,650 | 1,088 | 1,264 | |
| Richards 1982: Table 5.2, 145 | 1934 | 5.98 | 1,709 | 4.87 | 1,739 | 4.09 | 1,509 | 1,094 | 1,165 | |
| Richards 1982: Table 5.2, 145 | 1935 | 7.01 | 2,003 | 5.56 | 1,986 | 4.55 | 1,679 | 1,282 | 1,331 | |
| Richards 1982: Table 5.2, 145 | 1936 | 7.22 | 2,063 | 5.88 | 2,100 | 4.89 | 1,805 | 1,320 | 1,407 | |
| Richards 1982: Table 5.2, 145 | 1937 | 7.35 | 2,100 | 6.01 | 2,146 | 4.94 | 1,823 | 1,344 | 1,438 | |
| Richards 1982: Table 5.2, 145 | 1938 | 7.35 | 2,100 | 5.88 | 2,100 | 4.78 | 1,764 | 1,344 | 1,407 | |
| Richards 1982: Table 5.2, 145 | 1939 | 7.55 | 2,157 | 6.15 | 2,196 | | | 1,380 | 1,471 | |
| | AVERAGE | | 1,593 | | 1,649 | 4.43 | 1,634 | 1,071 | 1,164 | |
| | 95% CONFIDENCE LEVEL ± | | 150 | | 138 | | 55 | 72 | 74 | |
| | Average - 95% confidence level | | 1,443 | | 1,511 | | 1,579 | 999 | 1,090 | |
| | Average + 95% confidence level | | 1,743 | | 1,787 | | 1,689 | 1,143 | 1,238 | |
| | MAXIMUM | | 2,157 | | 2,196 | | 1,823 | 1,380 | 1,471 | |
| | MINIMUM | | 577 | | 764 | | 1,402 | 577 | 512 | |
| | STANDARD DEVIATION | | 418 | | 387 | | 123 | 201 | 206 | |

**Report 3.13a: Examples of the yield (kg/ha) of cereals for central North-Eastern Mediterranean and Balkans for the period 1934-1938**

| Reference | Country | Barley bushels/acre | Wheat bushels/acre | Pulses bushels/acre | Barley kg/ha | Wheat kg/ha | Beans kg/ha |
|---|---|---|---|---|---|---|---|
| Allbaugh 1953: 267, Table 267 | Crete | 15 | 12.8 | | 816 | 871 | 0 |
| Allbaugh 1953: 267, Table 267 | Albania | 19.3 | 15.6 | | 1,050 | 1,061 | 0 |
| Allbaugh 1953: 267, Table 267 | Greece | 17.6 | 13.4 | 9.6 | 958 | 912 | 653 |
| Allbaugh 1953: 267, Table 267 | Turkey | 20.4 | 14.7 | 12.5 | 1,110 | 1,000 | 680 |
| Hillman 1973: 226-227, Appendix 1 | Aşvan Turkey | | | | 410 | 630 | |
| Allbaugh 1953: 267, Table 267 | Yugoslavia | 17.8 | 16.9 | 14.7 | 969 | 1,150 | 800 |
| Allbaugh 1953: 267, Table 267 | Bulgaria | 25 | 18.8 | 8.2 | 1,361 | 1,279 | 446 |
| Allbaugh 1953: 267, Table 267 | Rumania | 12.2 | 14.4 | 8.6 | 664 | 980 | 468 |
| Allbaugh 1953: 267, Table 267 | Italy | 20.2 | 21.4 | 4.9 | 1,099 | 1,456 | 267 |
| | | | AVERAGE | | 937 | 1,038 | 414 |
| | | | 95% CONFIDENCE LEVEL ± | | 182 | 108 | 267 |
| | | | Average - 95% confidence level | | 755 | 930 | 147 |
| | | | Average + 95% confidence level | | 1,119 | 1,146 | 681 |
| | | | MAXIMUM | | 1,361 | 1,456 | 800 |
| | | | MINIMUM | | 410 | 630 | 0 |
| | | | STANDARD DEVIATION | | 279 | 166 | 385 |
| | | | AVERAGE DEVIATION | | 205 | 176.7 | 243.9 |

**Conversion rates**

| | | |
|---|---|---|
| 1 acre | 0.4 | ha |
| 1 bushell wheat | 27.215 | kg |
| 1 bushell barley | 21.772 | kg |
| 1 bushell pulses | 27.215 | kg |
| 1 ardeb lentils | 148 | kg |
| 1 khar/aroura barley | 171 | |
| 1 khar/aroura wheat | 215.9 | |
| 1 ardeb | 5.444 | bushels |
| 1 ardeb wheat | 150 | kg |
| 1 feddan | 0.42 | ha |
| 1 ardeb beans | 155 | kg |
| 1 ardeb barley | 120 | kg |

**Report 3.13B : Combined yield rates for Geece, Levant, NE.Med and Balkans (Reports )**

| | Barley kg/ha | Wheat kg/ha | Beans kg/ha | Lentils kg/ha | Combined pulses kg/ha |
|---|---|---|---|---|---|
| AVERAGE | 719 | 791 | 644 | 538 | 596 |
| 95% CONFIDENCE LEVEL ± | 73 | 98 | 68 | 56 | 49 |
| Average - 95% confidence level | 646 | 693 | 576 | 482 | 547 |
| Average + 95% confidence level | 792 | 889 | 712 | 594 | 645 |
| MAXIMUM | 1,670 | 2,480 | 1,098 | 925 | 1,098 |
| MINIMUM | 80 | 275 | 267 | 370 | 267 |
| STANDARD DEVIATION | 275 | 394 | 178 | 124 | 165 |
| AVERAGE DEVIATION | 194 | 281 | 126 | 86 | 122 |

**Report 3.13d Summary of ethnographic yield rates by crop**

| Region | Cypriot/Anatolia/Levant | | Egypt | |
|---|---|---|---|---|
| Crop | Yield kg/ha | ± 95% conf. level | Yield kg/ha | ± 95% conf. level |
| Barley | 713 | 63 | 1593 | 150 |
| Wheat | 63 | 83 | 1649 | 138 |
| Beans | 650 | 57 | 1634 | 55 |
| Lentils | 776 | 37 | N/A | N/A |
| Combined pulses | 1361 | 43 | N/A | N/A |

**Report 3.13c: Combined yield rates for Geece, Levant, NE.Med and Balkans (Reports ) excluding highest and lowest outlier values**

Enter 1 for all data, enter 2 to exclude max and min outliers = 2

| | Barley kg/ha | Wheat kg/ha | Beans kg/ha | Lentils kg/ha | Combined pulses kg/ha | Olive oil litres/ha |
|---|---|---|---|---|---|---|
| AVERAGE | 713 | 771 | 637 | 525 | 592 | 465 |
| 95% CONFIDENCE LEVEL ± | 63 | 83 | 57 | 37 | 43 | 291 |
| Average - 95% confidence level | 650 | 688 | 580 | 488 | 549 | 320 |
| Average + 95% confidence level | 776 | 854 | 694 | 562 | 635 | 316 |
| MAXIMUM | 1,361 | 1,630 | 976 | 719 | 976 | 512 |
| MINIMUM | 250 | 290 | 446 | 411 | 370 | 349 |
| STANDARD DEVIATION | 230 | 327 | 140 | 78 | 141 | 186 |
| AVERAGE DEVIATION | 169 | 247 | 101 | 63 | 108 | 349 |

**Report 3.14a: Yield rates (kg/ha and litres/ha) for olives and olive oil**

| Reference | Area | Period | Olives kg/ha | % oil extraction | Olive oil kg/ha | Olive oil litres/ha |
|---|---|---|---|---|---|---|
| Mattingly 1988b: 41. | Southern Spain | 2nd Century A.D. | 2,500 | 16 | 400 | 465 |
| Melena 1986: 105. | Knossos palace | 1 Linear B Tablets | 1,700 | 16 | 250 | 291 |
| Osborn 1987: 45-46. | Greece | Classical period | 1,719 | 16 | 275 | 320 |
| Mattingly 1988b: 45. | Tunisia (Sahel) | 1970's A.D. | 1,700 | 16 | 272 | 316 |
| Mattingly 1988b: 45. | Tunisia (Sfax) | 1970's A.D. | 2,750 | 16 | 440 | 512 |
| Amouretti 1986: 204. | North Med. | Post 1960 A.D. | 2,000 | 15 | 300 | 349 |
| Brun 1987: 208 footnote 30. | Italy | 1st Century B.C. | 1,000 | 16 | 160 | 186 |
| Rosen 1996: 28, Table 2. | Israel | 1930's-40's A.D. | 1,875 | 16 | 300 | 349 |
| Allbaugh 1953: 269. | Crete | 1930's A.D. | 1,375 | 16 | 220 | 256 |
| Allbaugh 1953: 269. | Crete | 1930's A.D. | 1,563 | 16 | 250 | 291 |
| Allbaugh 1953: 269. | Crete (Hierapetra) | 1948-1949 A.D. | 2,125 | 16 | 340 | 395 |
| Aschenbrenner: 1972, Table 4.2. | Greece (Messenia) | 1940's A.D. | 1,563 | 16 | 250 | 291 |
| Moreno 2007: 65. | Greece (Euonymon) | 1940's A.D. | 2,120 | 16 | 250 | 291 |
| Hutchinson 1968: 41. | Greece | 1930's A.D. | 1,125 | 16 | 180 | 209 |
| Hutchinson 1968: 41. | Italy and Turkey | 1940's A.D. | 938 | 16 | 150 | 174 |
| Bintliff 1974: 634. | Italy and Agaen | 1930's-50's A.D | 1,875 | 16 | 300 | 349 |
| Zertal 1996: 310 citing Lavi 1976: 207. | Southern Levant | 1970's A.D. | 2,500 | 16 | 400 | 465 |
| Heltzer: 1996: 79. | Israel | 1940's A.D. | 1,200 | 16 | 192 | 223 |
| Heltzer: 1996: 79. | Israel | 1940's A.D. | 2,550 | 16 | 408 | 474 |
| | AVERAGE | | 1,799 | | 281 | 327 |
| | 95% CONFIDENCE LEVEL ± | | 247 | | 33 | 45 |
| | Average - 95% confidence level | | 1,552 | | 248 | 282 |
| | Average + 95% confidence level | | 2,046 | | 314 | 372 |
| | MAXIMUM | | 2,550 | 16 | 408 | 512 |
| | MINIMUM | | 938 | 16 | 150 | 174 |
| | STANDARD DEVIATION | | 550 | 0 | 74 | 100 |

| Sources from antiquity | Average yield from sources in antiquity kg/ha | 271 |
|---|---|---|

**Report 3.14b**

**Conversion rates**

| | | |
|---|---|---|
| Weight of 1 litre olives = | 0.6 | kg |
| Density of olive oil Minimum = | 800 | kg/m3 |
| Density of olive oil Maximum = | 920 | kg/m3 |
| Average = | 860 | kg/m3 |
| Palnting rate/ha = | 100 | |

**Ras Shamra production**

| | | |
|---|---|---|
| Volume of 2 setlement tanks = | 0.768 | m3 |
| Average production = | 281 | kg/ha |
| **Area of olive trees required =** | **2.4** | **ha** |

1 Linear B tablets 902.9 great units of olives

**Report 3.14c: Olive oil yield on terraces at Euonymon**

| | | |
|---|---|---|
| Distance between olive trees | 7 | m |
| Spacing rows of Olive trees | 13.5 | m |
| No. rows in one sq km | 74 | |
| No. of trees per row one km long | 143 | |
| No. of trees/sq km | 10582 | |
| No. of trees/ha | 106 | |
| Yearly harvest | 20 | kg/tree |
| Yield | 2120 | kg/yr |

**Report 3.14d: Olive oild production in Cyprus for 1985/1988. European Community - International Olive Oil Council project (see Gregoriou, C. 2008 available from http://www.olivebusiness.com/articles/OBGuest/Oth/olives_and_olive_oil_in_cyprus.htm. Nicosia: Agricultural Research Institute) and Charis, G. 1979. The olive tree. Department of Agriculture, Nicosia, Cyprus, Publ. 19/1979.**

| Date | ha | Olives production kg | Yield of olives | % Extraction rate olive oil | Olive Oil kg/ha |
|---|---|---|---|---|---|
| 1985 | 6288 | 11500000 | 1829 | 16 | 293 |
| 1986 | 6287 | 12000000 | 1909 | 16 | 250 |
| 1987 | 6287 | 8000000 | 1272 | 16 | 275 |
| 1988 | 6300 | 18000000 | 2857 | 16 | 457 |
| 1989 | 6300 | 9000000 | 1429 | 16 | 229 |
| 1990 | 6300 | 10500000 | 1667 | 16 | 267 |
| 1991 | 6300 | 7000000 | 1111 | 16 | 178 |
| 1992 | 6100 | 19000000 | 3115 | 16 | 498 |
| **Average** | **6270** | **11875000** | **1899** | **N/A** | **306** |

| | Agrarian Manpower |
|---|---|
| Case 2: 0% olive oil plus 3.6% of fats for cooking from 'what if' workbook | **49802** |
| Case 1: 14.4% olive oil and 3.6% fats for consumption and cooking | **47490** |
| Difference | **2312** |
| % decrease in agricultural workload | **5** |

**Report 3.15a: Proportions of land assumed marginal, average and best land for Cyprus**

| Food category | Proportion farm land area into marginal, average and best | | | Proportion cereal and olive oil yield by the type of land (marginal, average and best) | | | | |
|---|---|---|---|---|---|---|---|---|
| | % of energy produced on marginal land | % of energy produced on average land | % of energy produced on best land | Yield ratio marginal land to normal land by food type | Yield ratio best land to normal land by food type | Yield Kg/ha marginal land by food type | Yield Kg/ha average land by food type | Yield Kg/ha best land by food type |
| Barley | 35 | 55 | 10 | -0.4 | 0.5 | 408 | 660 | 1,073 |
| Emmer wheat | 35 | 55 | 10 | -0.6 | 0.5 | 399 | 714 | 1,455 |
| Pulses and vegetables | 35 | 55 | 10 | -0.7 | 0.5 | 455 | 563 | 802 |
| Wine grapes* | 5 | 45 | 50 | -0.4 | 0.5 | 1,753 | 2,921 | 4,382 |
| Protein | | | | | | | | |
| Dairy | | | | | | | | |
| Olive oil | 20 | 65 | 15 | -0.4 | 0.5 | 181 | 272 | 398 |

1 cwt = 50.802 kg

* 23.5 cwt = 1193.847 kg    23.5 cwt/acre = 2921 kg/ha

* Land not fertilized in Crete 1947 A.D. produced a wine grape yield of 23.5 cwt/acre (Allbaugh 1953: 277, Table 50).

**Report 3.15b: Wastage rates**

| Assumptions | Loss in granary | Egypt: Total wastage in the field + granary, CASE A Ploughing | Egypt: Total wastage in the field + granary, CASE B Hoeing | Cyprus: Total wastage in the field + granary, CASE A Ploughing | Cyprus: Total wastage in the field + granary, CASE B Hoeing |
|---|---|---|---|---|---|
| Wastage rate of Barley % | 7.5 | 15 | 15 | 15 | 15 |
| Wastage rate of Emmer % | 7.5 | 15 | 15 | 15 | 15 |
| Wastage rate of pulses % | 7.5 | 15 | 15 | 15 | 15 |
| Wastage rate of olives % | | 10 | 10 | 10 | 10 |
| Wastage rate of grapes % | | 30 | 30 | 30 | 30 |

**Report 3.15c: Sowing ratios and percentages of sowing rates to harvest yield**

| | | | | 1 to 5 | 1 to 6 | 1 to 7.5 | 1 to 10 | 1 to 12.5 | 1 to 15 | 1 to 17.5 | 1 to 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 Sowing rate % Barley | Egypt | 10 | 10 | | | | | | | | |
| 1 Sowing rate % Wheat | Egypt | 10 | 10 | | | | | | | | |
| Sowing rate pulses | Egypt | 10 | 10 | | | | | | | | |
| 1 Sowing rate % Barley | Cyprus | 10 | 10 | 20 | 16.67 | 13.33 | 10 | 8 | 6.67 | 5.71 | 5 |
| 1 Sowing rate % Wheat | Cyprus | 10 | 10 | 20 | 16.67 | 13.33 | 10 | 8 | 6.67 | 5.71 | 5 |
| Sowing rate pulses | Cyprus | 10 | 10 | 20 | 16.67 | 13.33 | 10 | 8 | 6.67 | 5.71 | 5 |

1 Garnsey 1992: 148.

Marginal and best land set to ±95% conf. yields enter 0 | 1

**Base data from ethnographic analysis in Report 3.40**

Median = 1, av. = 2, 95% conf limit = 3 | 3

**Report 3.15d: Average yields from ethnographic data**

| Dry rain fed regions | Yield kg/ha marginal land | Yield kg/ha average land | Yield kg/ha best land |
|---|---|---|---|
| Barley | 408 | 660 | 1,073 |
| Wheat | 399 | 714 | 1,455 |
| Tot. pulses | 455 | 563 | 802 |
| Olive Oil | 181 | 272 | 398 |

| | |
|---|---|
| Best case yield improvement over average | 25 |
| Best case yield improvement over average | 25 |
| Best case yield improvement over average | 20 |
| Best case yield improvement over average | 15 |

**Report 3.15e: Cypriot best yield case for famine and glut analysis**

| Crop | Yield kg/ha marginal land | Yield kg/ha average land | Yield kg/ha best land |
|---|---|---|---|
| Barley | 510 | 825 | 1,342 |
| Wheat | 499 | 893 | 1,819 |
| Tot. pulses | 546 | 676 | 963 |
| Olive Oil | 209 | 313 | 458 |

**Report 3.15e: Worst yield case for famine and glut analysis**

| Crop | Yield kg/ha marginal land | Yield kg/ha average land | Yield kg/ha best land |
|---|---|---|---|
| Barley | 41 | 330 | 752 |
| Wheat | 40 | 357 | 1,019 |
| Tot. pulses | 46 | 282 | 482 |
| Olive Oil | 37 | 136 | 239 |
| **% of average due to lack of rain** | | | |
| Barley | 10 | 50 | 70 |
| Wheat | 10 | 50 | 70 |
| Tot. pulses | 10 | 50 | 60 |
| Olive Oil | 20 | 50 | 60 |

**Report 3.16a: Yields and sowing rates by food category and field type for Egypt**

| Food category | % of energy produced on marginal land | % of energy produced on average land | % of energy produced on best land | Yield ratio marginal land to normal land by food type | Yield ratio best land to normal land by food type | Yield Kg/ha marginal land by food type | Yield Kg/ha normal land by food type | Yield Kg/ha best land by food type |
|---|---|---|---|---|---|---|---|---|
| | Proportion farm land area into marginal, average and best | | | Proportion cereal and olive oil yield by the type of land (marginal, normal and best) | | | | |
| Barley | 25 | 70 | 5 | -0.4 | 0.5 | 703 | 1,057 | 1,313 |
| Emmer wheat | 15 | 65 | 20 | -0.4 | 0.5 | 687 | 1,156 | 1,395 |
| Pulses and vegetables | 15 | 65 | 20 | -0.7 | 0.5 | 917 | 1,582 | 1,781 |
| Wine grapes | 5 | 45 | 50 | -0.4 | 0.5 | 1,753 | 2,921 | 4,382 |
| Protein | | | | | | | | |
| Dairy | | | | | | | | |
| Sesame oil | 20 | 65 | 15 | Median = 1, av. = 2, 95% conf limit = 3 | | | 3 | |

**Report 3.16b**

| Assumptions | CASE A Ploughing | CASE B Hoeing |
|---|---|---|
| Wastage rate of Barley % | 15 | 15 |
| Wastage rate of Emmer % | 15 | 15 |
| Wastage rate of pulses % | 15 | 15 |
| Wastage rate of sesame seeds % | 0 | 0 |
| Wastage rate of grapes % | 0 | 0 |

**Report 3.16c: Sowing ratios and percentages of sowing rates to harvest yield**

1 Head 1995: 56-57.

| | CASE A | CASE B | 1 to 5 | 1 to 6 | 1 to 7.5 | 1 to 10 | 1 to 12.5 | 1 to 15 | 1 to 17.5 | 1 to 20 |
|---|---|---|---|---|---|---|---|---|---|---|
| Sowing rate % Barley | 10 | 10 | | | | | | | | |
| Sowing rate % Wheat | 10 | 10 | | | | | | | | |
| Sowing rate % Pulses | 10 | 10 | | | | | | | | |
| Sowing rate % Sesame | 10 | 10 | 20 | 16.67 | 13.33 | 10 | 8 | 6.67 | 5.71 | 5 |
| % fodder/fallow land to tot. arable | 10 | 10 | 20 | 16.67 | 13.33 | 10 | 8 | 6.67 | 5.71 | 5 |
| 1 Extraction rate % sesame oil | 41 | 41 | 20 | 16.67 | 13.33 | 10 | 8 | 6.67 | 5.71 | 5 |

**Assumption set 3.16c**

Marginal and best land set to ±95% conf. yields enter 1 | 1

**Base data from ethnographic analysis in Report 3.40**

**Report 3.16d: Average yields from Egyptian ethnographic data**

| Egypt | Yield kg/ha marginal land | Yield kg/ha average land | Yield kg/ha best land |
|---|---|---|---|
| Barley | 703 | 1,057 | 1,313 |
| Wheat | 687 | 1,156 | 1,395 |
| Pulses | 917 | 1,582 | 1,781 |

**Report 3.16e: Egypt best yield case for famine and glut analysis**

| | | Egypt | Yield kg/ha marginal land | Yield kg/ha average land | Yield kg/ha best land |
|---|---|---|---|---|---|
| Best case yield improvement over average | 25 | Barley | 879 | 1,322 | 1,642 |
| Best case yield improvement over average | 25 | Wheat | 859 | 1,445 | 1,744 |
| Best case yield improvement over average | 20 | Pulses | 1,101 | 1,899 | 2,138 |

**Report 3.16f: Worst yield case for famine and glut analysis**

| Crop | Yield kg/ha marginal land | Yield kg/ha average land | Yield kg/ha best land |
|---|---|---|---|
| Barley | 71 | 529 | 1,182 |
| Wheat | 69 | 578 | 1,256 |
| Pulses | 92 | 791 | 1,603 |
| % of average due to the innundation being too low or too high | | | |
| Barley | 10 | 50 | 90 |
| Wheat | 10 | 50 | 90 |
| Tot. pulses | 10 | 50 | 90 |

# Area of land required for fodder

**Report 3.17: Land required to produce barley and broad beans feed for oxen and donkeys**

**Report 3.17a**

| Ploughing assumptions | |
|---|---|
| 1 Av. area ploughed ha/pair oxen/day | 1.25 |
| Weight of oxen kg | 350 |
| No. of nucleat families per 100000 ca. | 17,889 |
| No. of oxen @ 1 yoked pair/farm | 35,778 |

| Straw production assumptions | | |
|---|---|---|
| 2 Modern prods. in US tons/acre = | 0.8 | 2 Lentils TDN% |
| Modern production in US kg/acre = | 725.8 | 2 Reference |
| Modern production in US kg/ha = | 1793.5 | |
| Ratio antiquity to modern = | 0.8 | 1 Reference |
| Antiquity straw yield rate kg/ha = | 1,435 | |

**Report 3.17d: Total Digestible Nutrients**

81 Peas

http://www.agr.gov.sk.ca/docs/reports/agri_view/AV200610_1.pdf

This assumes that dry residual matter from the leaves and pods were included so a lower figure of seems resonable

http://www.fao.org/docrep/007/j4504e/j4504e08.htm

| Conversion factors | | | | |
|---|---|---|---|---|
| 1 calorie | 4.184 | joules | | |
| 1 kcal | 4184 | joules | | |
| mega joule | 1,000,000 | joules | | |
| Calorific value hay | 17.4 | mega joule/kg | **4,159** | kcals/kg |
| Average hay | 17.4 | mega joule/kg | **4,159** | kcals/kg |
| Barley straw | 17.4 | mega joule/kg | **4,159** | kcals/kg |

**Report 3.17b**

| Average area dedicated to cereal crops excluding fodder | | |
|---|---|---|
| No. of nucleat families per 100000 ca. from Report 3.18 = | 17,889 | |
| Area of emmer and wheat for the Cypriot case from table 2.16A = | 34,602 | ha |
| Area of emmer and wheat for the Egyptan case from table 2.16A = | 25,644 | ha |
| Cypriot average area/family farm growing cereals excluding fodder = | **1.93** | **ha** |
| Egyptian average area/family farm growing cereals excluding fodder = | **1.43** | **ha** |
| Energy available from straw production from average Cypriot farm = | **11,518,558** | **kcals** |
| Energy available from straw production from average Egyptian farm = | **8,534,476** | **kcals** |
| **TOTAL =** | **20,053,034** | **kcals** |

| | | | | TDN Total Digestible Nutrients % |
|---|---|---|---|---|
| TDN calorific value of hay | 4,159 | kcals/kg | 0.47 | 47 |
| TDN calorific value of barley | 2,590 | kcals/kg | 0.78 | 78 |
| TDN calorific value of wheat | 3,320 | kcals/kg | 0.88 | 88 |
| TDN calorific value of pulses | 606 | kcals/kg | 0.75 | 75 |
| TDN calorific value of barley straw | 4,157 | kcals/kg | 0.41 | 41 |

**Report 3.17c**

| Case 2: Barley and broad bean requirements to feed one donkey/farm | |
|---|---|
| **Fodder requirements for a donkey** | **Fodder weight** |
| Crushed barley kg/day = | 0.449 |
| Broad beans kg/day = | 0.898 |
| Dry fodder kg/day = | 1.872 |
| Total weight dry barley straw kg/yr = | 683 |
| Total crushed barley kg/yr = | 164 |
| Total broad beans kg/yr = | 328 |
| | |
| **Total fodder kg/yr =** | **1,175** |
| No. of donkeys @ 1 donkey/family = | 17,889 |
| Fodder for one donkey kg/da | **3.2** |

| Total |
|---|
| 3.2 |

**Report 3.17e: Land required to feed one donkey/annum**

| Crop | Energy consumed kcals/yr | Cypriot area ha to grow fodder | Egypt area ha to grow fodder |
|---|---|---|---|
| Barley straw | 1,164,085 | 280 | 280 |
| Crushed barley | 424,760 | 0.25 | 0.16 |
| Broad beans | 198,768 | 0.58 | 0.21 |
| **Total** | **1,787,613** | **0.83** | **0.37** |

[2] Frank 1988
[3] Rao 1984: 542

[4] Foaden and Fletcher 1908: Vol. 2

**Report 3.17f: Analysis of donkey transport**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | **One Egyptian donkey** | | | | **One Cypriot donkey** | |
| | | | 1,787,613 | kcals/yr | | | 1,787,613 | kcals/yr |
| | | | 4898 | kcals/day | | | 4898 | kcals/day |
| | **EGYPT** | | | | **Cyprus** | | | |
| | **Pair of oxen, each 350 kg wt.** | | **One Donkey** | | **Pair of oxen, each 350 kg wt.** | | **One Donkey** | |
| Energy requirements | 15,591,450 | kcals/yr | 1,787,613 | kcals/yr | 15,591,450 | kcals/yr | 1,787,613 | kcals/yr |
| % satisfied by Alfalfa | 35 | % | 35 | % | 15 | % | 15 | % |
| Energy satisfied by dry straw | 10,134,443 | kcals/yr | 1,161,949 | kcals/yr | 13,252,733 | kcals/yr | 1,519,472 | kcals/yr |
| Energy satisfied by green alfalfa | 5,457,007 | kcals/yr | 625,664 | kcals/yr | 2,338,717 | kcals/yr | 268,141 | kcals/yr |
| Calorific content of Alfalfa | 2,557 | kcal/kg | 2,557 | kcal/kg | 2,557 | kcal/kg | 2,557 | kcal/kg |
| Wt of alfalfa required | 2,135 | kg | 245 | kg | 915 | kg | 105 | kg |
| Assume 15% wastage | 2,456 | kg | 282 | kg | 1,053 | kg | 121 | kg |
| Assume 10% seed corn | 2,702 | kg | 311 | kg | 1,159 | kg | 134 | kg |
| Alfalfa yield | 2,600 | kg/ha | 2,600 | kg/ha | 2,600 | kg/ha | 2,600 | kg/ha |
| Area of land required | 1.10 | ha | 0.12 | ha | 0.50 | ha | 0.06 | ha |
| Number of labour days per iugerum | 10.00 | days | 10.00 | days | 10.00 | days | 10.00 | days |
| 1 iugerum | 0.252 | ha | 0.252 | ha | 0.252 | ha | 0.252 | ha |
| Number of labour days per ha | 39.68 | days | 39.68 | days | 39.68 | days | 39.68 | days |
| Man-days of effort to grow alfalfa | **44** | **days** | **5** | man-days | **20** | **days** | **2** | **days** |
| No. of nuclear farms | 17,889 | | 17,889 | | 17,889 | | 17,889 | |
| Total area for alfalfa | 19,678 | ha | 2,147 | ha | 8,945 | ha | 1,073 | ha |
| Total man-days to grow alfalfa | 865,828 | days | 10,733 | man-days | 178,890 | days | 2,147 | days |
| **Total man-years to grow alfalfa** | **2,372** | **man years** | **29** | **man years** | **490** | **man years** | **6** | **man years** |

| | | | |
|---|---|---|---|
| Total agrarian man-years Cypriot ploughing/hoeing | | 43,938 | 52,817 |
| Cyprus | 59% | 46965 | 49078 |
| Total area required for fodder pair oxen + 1 donkey | | 21,825 | ha |
| Tot man-years required for fodder pair oxen + 1 donkey | | 2,402 | man-years |
| Total agrarian man-years Egyptian ploughing/hoeing | | 36,298 | 37,593 |
| Egypt | 59% | 39128 | 35839 |

| | | |
|---|---|---|
| 2 Oxen + 1 calf + 1 donkey Halstead and Jones 1989: 49 | 25 | donkey loads threshed straw + winnowed chaff |
| | 1875 | kg |
| Equivalent to | 1.5-3 ha | |

**Report 3.19a: Cost-benefit analysis for the use of oxen to reduce number of people working on the land**

Reference 1, Rao 1984: 542
Ref. 2, Thomas and Oearson 1986, Table 3
Reference
http://www.vt.tuwien.ac.at/biobib/fuel20.html
Reference
http://drought.wsu.edu/1100/1130.PDF

| | Case 1 | 1 Case 2 | 4 Case 3 | 5 Case 4 | Units |
|---|---|---|---|---|---|
| **Energy consumed by an ox per year** | **16** | **30** | **36** | **40** | gigajoules/yr |
| Energy required per ox | 3,832,000 | 7,185,000 | 8,622,000 | 9,580,000 | kcals/yr |
| Energy required per year by a pair of yoked oxen | 7,664,000 | 14,370,000 | 17,244,000 | 19,160,000 | kcals/yr |
| Energy required/yr by a pair of oxen uplifted by breeding overhead | 8,315,440 | 15,591,450 | 18,709,740 | 20,788,600 | |
| Weight of Oxen | 250 | 350 | 450 | 500 | kg |
| % of bullock weight that can be consumed as dry fodder/oxen/day | 1.25 | 1.25 | 1.25 | 1.25 | % |
| Maximum weight of dry matter that can be consumed/oxen/day | **3.13** | **4.38** | **5.63** | **6.25** | kg/day |
| Calorific value of barley straw | 17,400 | 17,400 | 17,400 | 17,400 | kjoules/kg |
| | 4,157 | 4,157 | 4,157 | 4,157 | kcals/kg |
| Percentage of straw that can be digested | 41 | 41 | 41 | 41 | % |
| Calorific value of straw that can be digested | 1,704 | 1,704 | 1,704 | 1,704 | kcals/kg |
| Annual calories that can be supplied by straw/pair oxen | 3,894,315 | 5,449,553 | 7,004,790 | 7,776,188 | kcals |
| Shortfall kcals that must be supplied by grain, beans or hay/pair oxen/yr | 3,769,685 | 8,920,447 | 10,239,210 | 11,383,812 | kcals |
| Calories consumed/yr by very active male/yr requiring 3780 kcals/day | 1,250,125 | 1,250,125 | 1,250,125 | 1,250,125 | kcals/yr |
| **Equivalent replacement of active men** | **3** | **7.1** | **8.2** | **9.1** | active men |

| | Case 1 | | Case 2 | | Case 3 | | Case 4 | |
|---|---|---|---|---|---|---|---|---|
| | Fodder crop kg/day | Pair oxen kg/yr | kg/day | Pair oxen kg/yr | kg/day | Pair oxen kg/yr | kg/day | Pair oxen kg/yr |
| **Barley** | 1.895 | 1,383 | 5.2 | 3,796 | 5.018 | 3,663 | 6.65 | 4,855 |
| **Beans** | 1.895 | 1,383 | 0.7 | 511 | 5.018 | 3,663 | 0.99 | 723 |
| **Straw** | 3.13 | 2,285 | 4.38 | 3,197 | 5.63 | 4,110 | 6.25 | 4,563 |
| | Ratio Barley to straw | 0.61 | | 1.19 | | 0.89 | | 1.06 |
| | Ratio Beans to straw | 0.61 | | 0.16 | | 0.89 | | 0.16 |

| | |
|---|---|
| TDN calorific value of barley kcals/kg | 2590 |
| TDN calorific value of beans kcals/kg | 606 |
| TDN Calorific value of straw kcals/kg | 4157 |

Calories equired for an active manual worker = 3,425
No. of nuclear families = 17,889

**Calories required to support a pair of oxen**

| | | |
|---|---|---|
| 1 gigajoule = | 0.2395 | million kcals/yr |
| 16 gigajoules = | 3.83 | million kcals/yr |
| 26 gigajoules = | 6.23 | million kcals/yr |
| 30 gigajoules = | 7.19 | million kcals/yr |
| 40 gigajoules = | 9.58 | million kcals/yr |

| | Case 1 | Case 2 | Case 3 | Case 4 | |
|---|---|---|---|---|---|
| Barley | 3,581,970 | 9,831,640 | 9,487,170 | 12,574,450 | kcals/yr |
| Beans | 838,098 | 309,666 | 2,219,778 | 438,138 | kcals/yr |
| Tibn | 3,894,315 | 5,449,553 | 7,004,790 | 7,776,188 | kcals/yr |
| | 8,314,383 | 15,590,859 | 18,711,738 | 20,788,776 | kcals/yr |
| **Iteration error %** | 0.01 | 0 | -0.01 | 0 | |

| **Area ha required to support pair of oxen** | **Cypriot** | **Egypt** |
|---|---|---|
| Area ha to grow barley on single farm = | 7.36 | 3.59 |
| Total area ha to grow barley over all the farms = | 131,663 | 64,222 |
| Area ha to grow beans on single farm = | 1.28 | 0.32 |
| Total area ha to grow beans over all the farms = | 22,898 | 5,724 |

| **Area required to support a single donkey** | **Cypriot** | **Egypt** |
|---|---|---|
| Area ha to grow barley on single farm = | 0.25 | 0.16 |
| Total area ha to grow barley over all the farms = | 4,472 | 2,862 |
| Area ha to grow beans on single farm = | 0.58 | 0.21 |
| Total area ha to grow beans over all the farms = | 10,376 | 3,757 |

| |
|---|
| **Cypriot** |
| **Total area ha to grow Barley + Pulses** |
| **8.64** |
| **Egypt** |
| **Total area ha to grow Barley + Pulses** |
| **4.28** |

| **Area of barley and beans grown for fodder for oxen** | **Cypriot** | **Egypt** | **Total** |
|---|---|---|---|
| **Area ha to grow crushed barley on single farm** | 7.61 | 3.75 | 11.36 |
| **Total area ha to grow barley over all the farms** | 136,135 | 67,084 | 203,219 |
| **Area ha to grow beans on single farm** | 1.86 | 0.53 | 2.39 |
| **Total area ha to grow beans over all the farms** | 33,274 | 9,481 | 42,755 |

| **Average yield** | |
|---|---|
| Yield barley D.F. | 660 |
| Yield barley Egypt | 1,057 |
| Yield pulses D.F. | 563 |
| Yield pulses Egypt | 1,582 |

# Area of land to feed 100,000

| Report 3.20a: Cyprus | ENERGY REQUIREMENTS Million kcals/yr/100000 people | | | | | AREA REQUIRED ha | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Food category | Calorific value kcals/kg from Table 2 | Energy produced on marginal land in Million kcals required/yr/ 100000 people | Energy produced on normal land in Million kcals required/yr/ 100000 people | Energy produced on best land in Million kcals required/yr/ 100000 people | Total weight of crops kg/yr/100000 people | Area of marginal land ha required/yr/ 100000 people | Area of normal land ha required/ yr/ 100000 people | Area of best land ha required/yr/ 100000 people | Total area ha required/ yr to feed 100000 people ploughing case | Total area ha required/ yr to feed 100000 people hoeing case |
| | | Total Energy (Report 8) prorated by land type | | | | Total Area prorated by land type Report 13 | | | CASE A | CASE B |
| Barley | 3,320 | 8,187 | 12,866 | 2,339 | **7,045,783** | 6,044 | 5,872 | 657 | 12,573 | 12,573 |
| Emmer wheat | 3,320 | 10,007 | 15,725 | 2,859 | **8,611,747** | 7,554 | 6,634 | 592 | 14,780 | 14,780 |
| Pulses (average) | 1,005 | 3,946 | 6,201 | 1,128 | **11,218,905** | 8,629 | 10,959 | 1,399 | 20,987 | 20,987 |
| **Wt of wastage products kg/yr/100,000** | | | | | **26,876,435** | **AREA GRAIN AND PULSES ha** | | | **48,340** | **48,340** |
| 1,056,895 | | | | | | Barley wastage replacement | | | 1,886 | 1,886 |
| 1,291,762 | | | | | | Wheat wastage replacement | | | 2,217 | 2,217 |
| 1,682,809 | | | | | | Pulses wastage replacement | | | 3,148 | 3,148 |
| **Wt of seed corn kg/yr/100,000** | | | | | | | | | | |
| 810,324 | | | | | | Next years seed corn requirement barley | | | 1,446 | 1,446 |
| 990,526 | | | | | | Next years seed corn requirement wheat | | | 1,700 | 1,700 |
| 1,290,439 | | | | | | Next years seed corn requirement pulses | | | 2,414 | 2,414 |
| | | | | | | **TOTAL AREA GRAIN AND PULSES ha** | | | **61,151** | **61,151** |
| Olive production | 8,571 | 3,081 | 10,013 | 2,311 | **1,797,340** | 1,986 | 4,295 | 677 | 6,958 | 6,958 |
| | | | | | | Olives wastage replacement | | | 696 | 696 |
| | | | | | | Taxation based on olive production plus wastage | | | | |
| Wine grapes | 744 | 52 | 465 | 517 | **1,389,785** | 40 | 214 | 159 | 413 | 413 |
| Protein | | | | 5,508 | **3,396,800** | Grapes wastage replacement | | | **124** | **124** |
| | | | | | | Taxation based on wine production plus wastage | | | 0 | 0 |
| Dairy | | | | 861 | **794,070** | **AREA ha** | | | **69,342** | **69,342** |
| | | | TOTALS | **86,066** | **34,254,430** | Area required for alfalfa fodder | | | 10,018 | 1,073 |
| | | | | | | **TOTAL AREA FOOD + FODDER ha** | | | **79,360** | **70,415** |

| | |
|---|---|
| **Average weight in kg food, wine, beer consumed/day/individual =** | **0.94** |
| **Average energy consuption kcals of food, wine, beer consumed/day/individual =** | **2,358** |

| **For tax assumptions av. yield kg/ha assumed** | | |
|---|---|---|
| Barley = | 660 | kg/ha |
| Wheat = | 714 | kg/ha |
| Olive oil = | 272 | kg/ha |
| Wine = | 2,921 | kg/ha |

| | |
|---|---|
| **Protein,dairy etc** | **6,369** |
| | 0 |
| Arable contribution of energy within the diet million kcals/yr | 79,697 |
| **Area of land for grain less seed corn** | **55,591** |

Summary

| Food category collated by area under cultivation | Cypriot ha | | Egypt ha | |
|---|---|---|---|---|
| | Ploughing | Hoeing | Ploughing | Hoeing |
| Consumerable cereals and pulses | 48,340 | 48,340 | 29,379 | 29,379 |
| Consumerable oil and wine | 7,371 | 7,371 | 103 | 103 |
| Wastage | 8,071 | 8,071 | 4,922 | 4,922 |
| Fodder | 10,018 | 1,073 | 21,825 | 2,147 |
| Seed corn | 5,560 | 5,560 | 3,430 | 3,430 |
| **TOTAL ha/100,000** | **79,360** | **70,415** | **59,659** | **39,981** |
| **TOTAL ha/total population** | **119,040** | **105,623** | **1,312,489** | **879,575** |
| **TOTAL km2/total population** | **1,190** | **1,056** | **13,125** | **8,796** |

**Report 3.20b: Mutton assumptions**

| | |
|---|---|
| 1 Total weight of mutton consumed kg | 441,150 |
| Wt (kg) of usable Mutton/animal (Lyman 1979: 542, Table 4) | 18 |
| No. of sheep/goats consumed | 24,508 |
| Flock size (Koster 1977: 277) | 50 |
| **No. of shepherds @ 1 man/flock** | **490** |

**Report 3.20c**

| Weight of crops required to feed 100,000 people/year | | |
|---|---|---|
| **Crop** | **Cypriot kg** | **Egypt kg** |
| Barley | 7,045,783 | 14,640,060 |
| Emmer wheat | 8,611,747 | 4,879,819 |
| Pulses and veg. | 11,218,905 | 13,702,488 |
| Oils and fats | 1,797,340 | 441,150 |
| Wine/grape juice | 1,389,785 | 346,774 |
| Meat protein | 3,396,800 | 2,547,600 |
| Dairy products | 794,070 | 352,920 |
| | **0** | **0** |
| **Total** | **14,167,201** | **207,785,613** |

**Report 3.20d**

| Crop | Ploughing | Hoeing |
|---|---|---|
| | **Area ha** | **Area ha** |
| Consumerable cereals and pulses | 29,379 | 29,379 |
| Consumerable oil and wine | 103 | 103 |
| Wastage | 4,922 | 4,922 |
| Alfalfa fodder | 21,825 | 2,147 |
| Seed corn | 3,430 | 3,430 |
| Taxation | 0 | 0 |
| **TOTAL ha** | **59,659** | **39,981** |

**Report 3.20e1: Area required to feed 100000 people**

| Crop | Cyprus area ha | Egypt area ha |
|---|---|---|
| Barley | 12,573 | 15,459 |
| Emmer wheat | 14,780 | 4,509 |
| Pulses | 20,987 | 9,411 |
| **Total** | **48,340** | **29,379** |

**Report 3.20f**

| | |
|---|---|
| Arable contribution of energy within the diet million kcals/yr | **78,835** |

**Report 3.20a1: Egypt**

| | | | | | |
|---|---|---|---|---|---|
| Number of families/100,000 (Report 3.22 below) | 17,889 | | | | |
| Total grain requirement kg/family/year = | 1,091 | **kg** | **kcals/annum** | **Total** | |
| Average weight kg of barley + emmer wheat required per worker/annum = | | 195 | 647,400 | 785,085 | |
| Average weight kg of barley + emmer wheat required per worker/annum = | | 137 | 137,685 | | |

| | |
|---|---|
| Protein kg/family/year | 142 |
| Oils/fats kg/family/year | 64 |
| Tot pulses requirement kg/family/year | 766 |
| **Total barley hectares including wastage/seed corn** | **19,854** |

If sesame analysis required enter 1

| Food type | Calorific value kcals/kg from Table 2 | Energy produced on marginal land in Million kcals required/yr/ 100000 people | Energy produced on normal land in Million kcals required/yr/ 100000 people | Energy produced on bestl land in Million kcals required/yr/ 100000 people | Tot. wt. of crops kg/yr/100000 people | Area of marginal land ha required/yr/ 100000 people | Area of normal land ha required/ yr/ 100000 people | Area of best land ha required/yr/ 100000 people | Total area ha required/ yr to feed 100000 people ploughing case | Total area ha required/ yr to feed 100000 people hoeing case |
|---|---|---|---|---|---|---|---|---|---|---|
| | **ENERGY REQUIREMENTS Million kcals/yr/100000 people** | | | | | **AREA REQUIRED ha** | | | | |
| | | Total Energy (Report 8) prorated by land type | | | | Total Area prorated by land type Report 15 | | | **CASE A** | **CASE B** |
| Barley | 3,320 | 12,151 | 34,024 | 2,430 | **14,640,060** | 5,206 | 9,696 | 557 | 15,459 | 15,459 |
| Emmer wheat | 3,320 | 2,430 | 10,531 | 3,240 | **4,879,819** | 1,065 | 2,744 | 700 | 4,509 | 4,509 |
| Pulses (average) | 1,005 | 2,066 | 8,951 | 2,754 | **13,702,488** | 2,242 | 5,630 | 1,539 | 9,411 | 9,411 |
| **Wt of wastage products kg/yr/100,000** | | | | | **33,222,367** | **AREA GRAIN AND PULSES ha** | | | **29,379** | **29,379** |
| 2,452,795 | | | | | | Barley wastage replacement | | | 2,590 | 2,590 |
| 817,091 | | | | | | Wheat wastage replacement | | | 755 | 755 |
| 2,296,124 | | | | | | Pulses wastage replacement | | | 1,577 | 1,577 |
| **Wt of seed corn kg/yr/100,000** | | | | | | | | | | |
| 1,709,380 | | | | | | Next years seed corn requirement barley | | | 1,805 | 1,805 |
| 569,258 | | | | | | Next years seed corn requirement wheat | | | 526 | 526 |
| 1,600,152 | | | | | | Next years seed corn requirement pulses | | | 1,099 | 1,099 |
| | | | | | | **TOTAL AREA GRAIN AND PULSES ha** | | | **37,731** | **37,731** |
| wine | 744 | 13 | 116 | 129 | **346,774** | 10 | 53 | 40 | 103 | 103 |
| Protein | | | | 3,701 | **2,547,600** | | | | | |
| Oils and fats | | | | 3,099 | **441,150** | | | | | |
| Dairy | | | | 430 | **352,920** | | | | | |
| | | | **TOTALS** | **86,065** | **36,910,811** | **AREA ha** | | | **37,834** | **37,834** |
| | | | | **Protein,dairy etc** | **7,230** | Area required for alfalfa fodder | | | 21,825 | 2,147 |
| | | | | | | **TOTAL AREA FOOD + FODDER ha** | | | **59,659** | **39,981** |

**Report 3.20b1: Assumptions based on Muella 1975: 253.**

| | |
|---|---|
| Calories consumed in beer million kcals/yr/100000 people = | **4,389** |
| % proportion of the calories of barley for beer to total barley = | **9** |
| Total area under barley cultivation allocated to beer production ha = | **1,787** |
| Average weight in kg food, wine, beer consumed/day/individual = | **1.01** |
| Average energy consuption kcals of food, wine, beer consumed/day/individual = | **2,358** |

Sesame assumptions (Serpico 2000:390, Salunkhe et al 1992: 373 and Eckey 1954: 754-756, )

| | | | | |
|---|---|---|---|---|
| Extraction rate = | 0.216 | litre/kg | % Oil content min. | 37 |
| density sesame oil = | 900 | kg/m3 | % Oil content max. | 63 |
| Extraction efficiency = | 41 | % | Av. % oil content | 50 |
| Calorific value of sesame oil = | 8571 | kcals/kg | | |

[1] Assumption is that meat is excluded from children under 3

**Report 3.20g: Summary of the weight, volume and area of land under grain and pulses cultivation per 100,000 population correlated by the proportions stored in local rural and state granaries.**

| Crop | Egypt Wt kg | Egypt Vol m3 |
|---|---|---|
| Barley | 14,640,060 | 24,040 |
| Emmer wheat | 4,879,819 | 6,346 |
| Pulses | 13,702,488 | 27,405 |
| **Total/100,000** | **33,222,367** | **57,790** |
| **plus wastage 15% + seed corn 10%** | | |
| Barley | 4,162,175 | 6,834 |
| Emmer wheat | 1,386,349 | 1,803 |
| Pulses | 3,896,276 | 7,793 |
| **Total/100,000** | **9,444,801** | **16,430** |
| **Harvest buffer to smooth out harvests at 10%** | | |
| Barley | 1,880,224 | 3,087 |
| Emmer wheat | 626,617 | 815 |
| Pulses | 1,759,876 | 3,520 |
| **Total/100,000** | **4,266,717** | **7,422** |
| **Total storage requirements** | | |
| Barley | 20,682,459 | 33,961 |
| Emmer wheat | 6,892,785 | 8,963 |
| Pulses | 19,358,641 | 38,717 |
| **Total/100,000** | **46,933,884** | **81,642** |
| **Total/popl'n** | **1,032,545,456** | **1,796,123** |

**Report 3.20h: Seed corn analysis**

| Crop | Egypt | Cyprus |
|---|---|---|
| Land required for barley seed corn ha | 1,805 | 1,446 |
| Land required for wheat seed corn ha | 526 | 1,700 |
| Weight of barley seed kg | 1,907,885 | 954,360 |
| Weight of wheat seed kg | 608,056 | 1,213,800 |

| Economic sector | Workforce |
|---|---|
| Value add sector | 13,320 |
| Agrarian workforce | 37,205 |
| Domestic shelter | 920 |
| Domestic pottery | 66 |
| Cloth workers | 14,659 |
| Elite | 2,970 |
| Non-productive 55 + under 6 | 30,860 |
| Total | **100,000** |
| Non-value add | 86,680 |
| Value add sector | 13,320 |
| Total | **100,000** |

| | | |
|---|---|---|
| Density of barley | 609 | kg/m3 |
| Density of wheat | 769 | kg/m3 |
| Density of pulses | 500 | kg/m3 |

**Report 3.20e2: Area of barley, emmer wheat, and pulses including seed corn and wastage**

| Crop + seed corn + wastage | Cyprus area ha | Egypt area ha |
|---|---|---|
| Barley | 15,905 | 19,854 |
| Emmer wheat | 18,697 | 5,790 |
| Pulses | 26,549 | 12,087 |
| **Total** | **61,151** | **37,731** |

| | |
|---|---|
| Area of land under cultivation for grain and pulses + seed corn + wastage ha | **37,731** |

**Report 3.20i: Summary of the weight, volume and area of land under grain and pulses cultivation per 100,000 population correlated by the proportions stored in local rural and state granaries.**

| Per 100,000 population | Percentage | Wt kg | Vol m3 | Area ha |
|---|---|---|---|---|
| Crops in state granaries for value add workers | 15 | 7,040,083 | 12,246 | 5,660 |
| Crops stored in state granaries to minimise famines/gluts | 10 | 4,693,388 | 8,164 | 3,773 |
| Grain/pulses stored in rural granaries | 75 | 35,200,413 | 61,231 | 28,298 |
| **Totals** | **100** | **46,933,884** | **81,642** | **37,731** |
| **Total population 2.2 million** | **Percentage** | **Wt kg** | **Vol m3** | **Area ha** |
| Crops in state granaries for value add workers | 15 | 154,881,818 | 269,418 | 124,512 |
| Crops stored in state granaries to minimise famines/gluts | 10 | 103,254,546 | 179,612 | 83,008 |
| Grain/pulses stored in rural granaries | 75 | 774,409,092 | 1,347,092 | 622,562 |
| **Totals** | **100** | **1,032,545,456** | **1,796,123** | **830,082** |

| | | | | | | |
|---|---|---|---|---|---|---|
| Manpower to build one Ramesseum | **923** | man-years | No of Ramesseums | **109** | **Total man-years** | **100,607** |
| Manpower to build one Amarna granary | **0.335** | man-years | No. of Amarna type granaries | **189,066** | **Total man-years** | **63,337** |
| | | | Size of Ramasseum granary m3 | 16,522 | | |
| | | | Size of Amana granary m3 | 9.5 | | |

**Report 3.20j**

| | |
|---|---|
| Load carried by a donkey kg | **75** |
| Total number. of return donkey journeys/100,000 popl'n | **625,785** |
| Total no. of return donkey journeys/total population | **13,767,273** |

**Report 3.20k: Transport manpower costs harvesting and moving grain to local and state granaries**

| | | |
|---|---|---|
| Man-days/ha to harvest and transport grain/pulses to rural granaries | **24** | man-days/ha |
| Area of land supporting rural granaries | **622,562** | ha |
| Total man-years | **48,511** | man-years |
| Wt of state and temple grain and pulses kg | 258,136,364 | kg |
| Carrying capacity of a donkey kg | 75 | kg |
| No. of individual donkeys journies required to carry the crops | 3,441,819 | |
| Assume number of donkeys per donkey train | 10 | |
| Number of donkey trains within the caravan | 1 | |
| No of handlers required to control donkey team | 2 | |
| Total number of handlers/journey + loaders and unloaders | 5 | |
| Total no. of donkey train journeys | 344,182 | |
| Distance to transport grain and pulses to river and state granaries km | 2.5 | 5 |
| Return journey distance km | 5 | 10 |
| Total distance travelled km | 1,720,910 | 3,441,819 |
| Speed of donkey team mph | 2.8 | 2.8 |
| Speed of donkey team km/hr | 4.48 | 4.48 |
| Elapse time of journey hrs | 384,132 | 768,263 |
| Length of shift hrs | 12 | 12 |
| Watering/rest period hrs | 1 | 1 |
| Watering/rest stops/day | 3 | 3 |
| Length of shift less watering//rest period hrs | 9 | 9 |
| Days to move harvest from the farms to harbour queys | 42,682 | 85,363 |
| Tot. man-days for controlling donkey teams from farms/river keys | 213,410 | 426,815 |
| **Tot. man-years for controlling donkey teams from farms/river keys** | **693** | **1,386** |
| Vol. of state and temple grain and pulses | 1,796,123 | m3 |
| Carrying capacity of ship in Amiens Papyrus Janssen 2004: 27 | 989.38 | sacks |
| | 76 | m3 |
| Number of journeys | 23633 | |
| Crew stated in Amien papyri (BV, 12) Janssen 2004: 29 | 15 | |
| Assum return journey 5 days with loading and unloading | 2 | days |
| Shipping effort | **2,302** | **man-years** |
| Unloading/loading 1 donkey trains at the harbour key and filling state granary | 1.5 | day |
| No. of men required per boat load | 8 | |
| Man-years filling up state granaries | **921** | **man-years** |
| Total shipping, transport, and loading state granaries | **5,302** | **man-years** |
| Grand total workload | **53,813** | man-years |
| Corvee labour required for one month | **645,752** | **corvee labour** |
| Full time agrarian workers | 37,205 | individuals |
| Full time agrarian to support total population | 818,510 | individuals |
| Total workers on the land in the harvest period | **1,464,262** | individuals |

# FAMILY SIZE CALCULATION

**Report 3.21a: Size of a nuclear family as derived evidence from Ugarit texts**

| | Husband | Wife | Sons | Daughters | Son or daughter | Brothers | Daughters in-law | Total Adults | Children + Elderly | Grand Total |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 2 | | | | | 4 | 1.7 | 5.7 |
| 2 | 1 | 1 | 1 | | | 1 | | 4 | 1.7 | 5.7 |
| 3 | 1 | 1 | 2 | | | | | 4 | 1.7 | 5.7 |
| 4 | 1 | 1 | 1 | | | | | 3 | 1.3 | 4.3 |
| 5 | 1 | 1 | | | 1 | | | 3 | 1.3 | 4.3 |
| 6 | 1 | 1 | | | 1 | | | 3 | 1.3 | 4.3 |
| 7 | 1 | 1 | 2 | | | | | 4 | 1.7 | 5.7 |
| 8 | 1 | 1 | 2 | | | | | 4 | 1.7 | 5.7 |
| 9 | 1 | 1 | 1 | | | | | 3 | 1.3 | 4.3 |
| 10 | 1 | 1 | 1 | 1 | | | | 4 | 1.7 | 5.7 |
| 11 | 1 | 1 | 2 | | | | | 4 | 1.7 | 5.7 |
| 12 | 1 | 1 | 1 | | | | | 3 | 1.3 | 4.3 |
| 13 | 1 | 1 | 1 | | | | | 3 | 1.3 | 4.3 |
| 14 | 1 | 1 | 2 | 1 | | | | 5 | 2.2 | 7.2 |
| 15 | 1 | 1 | 1 | | | | 1 | 4 | 1.7 | 5.7 |
| 16 | 1 | 1 | 1 | 1 | | | | 4 | 1.7 | 5.7 |
| 17 | 1 | 1 | 1 | | | | 1 | 4 | 1.7 | 5.7 |
| 18 | 1 | 1 | 3 | | | | 3 | 8 | 3.5 | 11.5 |
| Total | 18 | 18 | 24 | 3 | 2 | 1 | 5 | 71 | 31 | 102 |
| Uplift % for children under 9 from Report 0 | | 29.92 | | | | | | | | |
| Uplift % for elderly from Report 0 | | 13.77 | | | | | | | | |
| Av. family size | 1 | 1 | 1.33 | 0.17 | 0.11 | 0.06 | 0.28 | 3.95 | 1.72 | 5.67 |
| Av. family prorated to 100 | 0.98 | 0.98 | 1.3 | 0.17 | 0.11 | 0.06 | 0.27 | 3.87 | 1.72 | 5.59 |
| | | | | | | | | | | 6 |

See also Kemp 1991: 157 who proposes an average nuclear family size =6.

**Report 3.21b: Number of nuclear families and farms in the Egyptian agrarian sector of the economy**

No. nuclear farms with family size/100000 population = 17,889 **Linked to BRONZE SS**

| | | |
|---|---|---|
| East. Med. Cypriot and North Eastern Med. regions average farm size based on arable plus olive groves and vinyards | 3.9 | ha |
| Egyptian average farm size based on arable plus olive groves and vinyards | 2.1 | ha |
| Cypriot and North Eastern Med. regions average farm size based on total arable land used for barley, wheat and pulses | 3.4 | ha |
| Egyptian average farm size based on total arable land used for barley, wheat and pulses | 2.1 | ha |
| Cypriot and NE Med. average farm size based on arable land used for barley, wheat and pulses for human consumption only | 2.7 | ha |
| Egyptian average farm size based on arable land used for barley, wheat and pulses for human consumption only | 1.64 | ha |
| Number of nucluate families/100000 | 17,889 | |

**Report 3.21c**

| | | |
|---|---|---|
| No. of families /100,000 population | 17,889 | |
| | Egypt total kg/100,000 | Egypt/family kg |
| Pulses | 13,702,488 | 766 |
| Protein/oils et al | 3,688,444 | 206 |
| grain only | 19,519,879 | **1,091** |
| **Ramesses III donations to temples** | | |
| Average yield | 714 | kg/ha |
| Area of land | 300,000 | ha |
| Weight of grain | 214,200,000 | kg |
| No. of families | 196,000 | |

**Report 3.21d: Deir el Medina grain Rations**

| Rank | Wheat | | | | | |
|---|---|---|---|---|---|---|
| Chief foreman | 66 | Khar = | 5,069 | litres = | 3,898 | Kg |
| Skilled worker | 48 | Khar = | 3,686 | litres = | 2,835 | Kg |
| Guard | 24 | Khar = | 1,843 | litres = | 1,417 | Kg |
| Porter | 12 | Khar = | 922 | litres = | 709 | Kg |
| **Rank** | **Barley** | | | | | |
| Chief foreman | 22 | Khar = | 1,690 | litres | 1,029 | Kg |
| Skilled worker | 16 | Khar = | 1,229 | litres | 748 | Kg |
| Guard | 8 | Khar = | 614 | litres | 374 | Kg |
| Porter | 4 | Khar = | 307 | litres | 187 | Kg |

| | | |
|---|---|---|
| Density of dry barley = | **609** | kg/m3 |
| Density of dry wheat = | **769** | kg/m3 |
| 1 litre = | **0.001** | m3 |
| 1 khar = | **76.8** | litres |

| | | |
|---|---|---|
| Tot for chief foreman | 4,927 | Kg |
| Tot. skilled worker | 3,583 | Kg |
| Total for guard | 1,791 | Kg |
| Total for porter | 896 | Kg |
| Porter shortfall | 195 | Kg |

**Report 3.21e**

Assumption 1 rations assumed to be 70 % of those at Deir el-Medina, ratio 0.7

| Rank | Wheat | | | | | | |
|---|---|---|---|---|---|---|---|
| Chief foreman | 46 | Khar = | 3,548 | litres = | 2,729 | Kg | |
| Skilled worker | 34 | Khar = | 2,580 | litres = | 1,985 | Kg | |
| Guard | 17 | Khar = | 1,290 | litres = | 992 | Kg | |
| Porter | 8 | Khar = | 645 | litres = | 496 | Kg | |
| **Rank** | **Barley** | | | | | | |
| Chief foreman | 15 | Khar = | 1,152 | litres | 702 | Kg | |
| Skilled worker | 11 | Khar = | 845 | litres | 514 | Kg | |
| Guard | 6 | Khar = | 461 | litres | 281 | Kg | |
| Porter | 3 | Khar = | 230 | litres | 140 | Kg | |
| **Rank** | **Total Grain** | | | | | | Energy kcals |
| Chief foreman | 61 | Khar = | 4,700 | litres | 3,431 | Kg | 11,390,920 |
| Skilled worker | 45 | Khar = | 3,425 | litres | 2,499 | Kg | 8,296,680 |
| Guard | 23 | Khar = | 1,751 | litres | 1,273 | Kg | 4,226,360 |
| Porter | 11 | Khar = | 875 | litres | 636 | Kg | 2,111,520 |
| | | | | | 7,839 | | 26,025,480 |

**Report 3.21f**

| Rank within crew | Volume (litres) of surplus grain for Deir el-Medina | Volume (m3) of surplus grain for Deir el-Medina |
|---|---|---|
| Chief foreman | 4,988 | 5.0 |
| Skilled worker | 3,241 | 3.2 |
| Guard | 910 | 0.9 |
| Porter | N/A no surplus | N/A no surplus |

**Report 3.21g**

| Weight of crops required to feed 100,000 people/year | | |
|---|---|---|
| **Crop** | **Cypriot kg** | **Egypt kg** |
| Barley | 7,045,783 | 14,640,060 |
| Emmer wheat | 8,611,747 | 4,879,819 |
| Pulses and veg. | 11,218,905 | 13,702,488 |
| Oils and fats | 1,797,340 | 441,150 |
| Wine/grape juice | 1,389,785 | 346,774 |
| Meat protein | 3,396,800 | 2,547,600 |
| Dairy products | 794,070 | 352,920 |
| **Total** | **34,254,430** | **36,910,811** |

**Report 3.21h: Deir el-Medina rations**

| | |
|---|---|
| Grain required per family kg | 1,091 |
| Assume 2/3 emmer kg | 727 |
| Assume 1/3 barley kg | 364 |
| Density of dry emmer wheat kg/m3 | 769 |
| Density of dry barley kg/m3 | 609 |
| Volume required for emmer storage m3 | 0.9 |
| Volume required for barley storage m3 | 0.6 |
| **Total m3** | **1.5** |

**Surplus grain rations kg per year per family for each crew position assuming annual requirement to feed a family is 1090 kg**

| Rank within crew | Deir el-Medina tomb workers | Other non-agrarian state workers with rations @ 70% of Deir el M'na |
|---|---|---|
| Chief foreman | 3,836 | 2,340 |
| Skilled worker | 2,492 | 1,408 |
| Guard | 700 | 182 |
| Porter | -195 | -455 |

**Report 3.21L**

| | | |
|---|---|---|
| Volume grain in the Ramaesseum | 16,552 | m3 of grain |
| Wt of grain in the Ramesseum if wheat | 12,728,488 | kg of emmer wheat |
| Wt of grain in the Ramesseum if barley | 10,080,168 | kg of barley |

**Report 3.21i**

| Rank within crew | Assumed organisational profiles of the crews | | | |
|---|---|---|---|---|
| | Profile 1 | Profile 2 | Profile 3 | Profile 4 |
| Chief foreman | 1 | 1 | 2 | 2 |
| Skilled worker | 10 | 20 | 46 | 75 |
| Guard | 1 | 1 | 2 | 2 |
| Porter | 1 | 3 | 5 | 6 |
| **Crew size** | **13** | **25** | **55** | **85** |
| **Surplus rations kg/yr/crew** | **16,147** | **29,317** | **67,537** | **107,914** |
| | 16,147 | | | |

| Size of assumed state workforce | Size of crew | | | |
|---|---|---|---|---|
| | Profile 1 | Profile 2 | Profile 3 | Profile 4 |
| | **13** | **25** | **55** | **85** |
| | Number of crews for a given size of state manual workers | | | |
| 50,000 | 3,846 | 2,000 | 909 | 588 |
| 100,000 | 7,692 | 4,000 | 1,818 | 1,176 |
| 200,000 | 15,385 | 8,000 | 3,636 | 2,353 |
| 300,000 | 23,077 | 12,000 | 5,455 | 3,529 |

| Size of assumed state workforce | Tot surplus grain kg entering the informal market | | | |
|---|---|---|---|---|
| | Profile 1 | Profile 2 | Profile 3 | Profile 4 |
| 50,000 | 62,101,362 | 58,634,000 | 61,391,133 | 63,453,432 |
| 100,000 | 124,202,724 | 117,268,000 | 122,782,266 | 126,906,864 |
| 200,000 | 248,421,595 | 234,536,000 | 245,564,532 | 253,921,642 |
| 300,000 | 372,624,319 | 351,804,000 | 368,414,335 | 380,828,506 |

| Rank within crew | Surplus rations for each crew kg/yr | | | |
|---|---|---|---|---|
| | Profile 1 | Profile 2 | Profile 3 | Profile 4 |
| Chief foreman | 2,340 | 2,340 | 4,680 | 4,680 |
| Skilled worker | 14,080 | 28,160 | 64,768 | 105,600 |
| Guard | 182 | 182 | 364 | 364 |
| Porter | -455 | -1,365 | -2,275 | -2,730 |
| **Total** | **16,147** | **29,317** | **67,537** | **107,914** |

| Size of assumed state workforce | Equivalent number of Ramesseum granaries if emmer wheat is stored | | | |
|---|---|---|---|---|
| | Profile 1 | Profile 2 | Profile 3 | Profile 4 |
| 50,000 | 4.9 | 4.6 | 4.8 | 5 |
| 100,000 | 9.8 | 9.2 | 9.6 | 10 |
| 200,000 | 19.5 | 18.4 | 19.3 | 19.9 |
| 300,000 | 29.3 | 27.6 | 28.9 | 29.9 |

| Size of assumed state workforce | Equivalent number of Ramesseum granaries if barley is stored | | | |
|---|---|---|---|---|
| | Profile 1 | Profile 2 | Profile 3 | Profile 4 |
| 50,000 | 6.2 | 5.8 | 6.1 | 6.3 |
| 100,000 | 12.3 | 11.6 | 12.2 | 12.6 |
| 200,000 | 24.6 | 23.3 | 24.4 | 25.2 |
| 300,000 | 37 | 34.9 | 36.5 | 37.8 |

# MANPOWER CALCULATION

**Report 3.22a: Transport assumptions and man-days/ha required for transport of harvest from the fields to the crop preparation area using donkeys**

| | | |
|---|---|---|
| Assume % distance travelled by donkey radially from centre of the farm = | 80 | % |
| 7-12 donkey loads/stemma required to transport loads straw and grain to the threshing floor (Halstead and Jones 1989:47) = | 8.5 | Average number of loads/stemma |
| No of donkey loads = | 85 | loads/ha |
| Minimum man-days to bind, load and unload sheaves at the threshing shed | 2 | hours |
| Maximum man-days to bind, load and unload sheaves at the threshing shed | 3 | hours |
| Average time to bind, load and unload sheaves at the threshing shed | 2.5 | hours |

**Conversion rates**

| | | |
|---|---|---|
| 1 stremma = | 0.1 | ha |
| 1 ha = | 10000 | m2 |
| 1 ha = | 0.01 | km2 |

| Activity | Ploughing case | | Hoeing case | | Units | |
|---|---|---|---|---|---|---|
| | Eypt | Cypriot | Eypt | Cypriot | | |
| Average farm area Cypriot | 2.1 | 3.4 | 2.1 | 3.4 | ha | |
| Average farm area Cypriot | 0.021 | 0.034 | 0.021 | 0.034 | km2 | |
| Speed of donkey km/hr | 3.2 | 3.2 | 3.2 | 3.2 | km/hr | Granary to river |
| Av. distance travelled to and from field km | 0.13 | 0.17 | 0.13 | 0.17 | km | |
| Total distance travelled per return journey km | 11.1 | 14.5 | 11.1 | 14.5 | km | |
| Hours in transit from the field to the threshing floor | 3.5 | 4.5 | 3.5 | 4.5 | hrs | |
| Binding, loading and unloading time | 2.5 | 2.5 | 2.5 | 2.5 | hrs/return trip | |
| Loading and unloading time | 212.5 | 212.5 | 212.5 | 212.5 | hrs | |
| Total transport time plus loading/unload | 216 | 217 | 216 | 217 | hrs | |
| Hours worked/day | 9 | 9 | 9 | 9 | hr | |
| **Total transport man-days** | **24** | **24.1** | **24** | **24.1** | **man-days/ha** | Linked to Shelter SS Report 4.1 |
| | **24** | | | | | |

**Report 3.22b: Irrigation Man-power requirements**

| **Irrigation Manpower requirements** | |
|---|---|
| Water requirement (Breasted 1906: 8, footnote 1) tons/acre/day | 18 |
| kg/ha/day | 45,191 |
| Discharge from a typical shaduf (Foaden and Fletcher 1908: 178) m3/hr | 8.4 |
| kg/hr | 8,400 |
| Corrected for lower efficiency in LBA kg/hr | 5,880 |
| Total hours required to water one ha/day | 7.7 |
| Utilised hours worked per day | 9 |
| Irrigation man-power required/day/ha | 0.86 |
| Total irrigation period days | 100 |
| **Man-days/ha for the growing period** | **86** |
| % reduction in water requirement for Cyprus compared with Egypt | 25 |
| **Total man-days//ha for growing season utilised** | **22** |

| | | |
|---|---|---|
| 1 feddan = | 0.42 | ha |
| Irrigation of land for flax in 1813 A.D. = | 72 | man-days/feddan |
| Irrigation of land for flax in 1813 A.D. = | 171 | man-days/ha |

**Ref.**
Richards 1982: Table 2.1, 17.

**Conversion factors**

| | | |
|---|---|---|
| 1 acre = | 0.4047 | ha |
| 1 imperial ton = | 2240 | lbs |
| | 1016.05 | kg |
| 1 imperial ton/acre = | 1016.05 | kg/acre |
| | 2510.63 | kg/ha |
| 1 feddan = | 0.42 | ha |
| density of water = | 1000 | kg/m3 |

**Assumption**

| | | |
|---|---|---|
| % efficiency of LBA shaduf compared to 1908 shaduf due to poorer materials and construction | 70 | % |

**Report 3.23a: Threshing and winnowing assumptions**

**Threshing and winnowing of wheat (Cypriot conditions)**

| **Adapted source data Watson 1979: 82.** | **Wheat** | | | | |
|---|---|---|---|---|---|
| | **Av. hrs/man** | **Av. hrs/kg** | **Av. yield kg/ha** | **Hrs/ha** | **Man-days/ha** |
| Threshing using 5 oxen | 13.5 | 0.045 | 714 | 32.13 | 3.2 |
| Fork winnowing | 3.5 | 0.0117 | 714 | 8.35 | 0.8 |
| Sieve Winnowing | 1.75 | 0.0058 | 714 | 4.14 | 0.4 |
| **TOTAL** | **18.75** | **0.0625** | **714** | **44.62** | **4.4** |
| **Adapted from Simms and Russell 1997: 700, Table 3.** | **Wheat** | | | | |
| | **Av. hrs/man** | **Av. hrs/kg** | **Av. yield kg/ha** | **Hrs/ha** | **Man-days/ha** |
| Threshing + winnowing | | | | | **5** |
| **Adapted source data US Depart' of Labour 1899** | **Wheat** | | | | |
| | **Av. hrs/20 US bu** | **Av. hrs/kg** | **Av. yield kg/ha** | **Hrs/ha** | **Man-days/ha** |
| Threshing | 13.33 | 0.0246 | 1116.2 | 27.46 | 2.7 |
| Winnowing | 11 | 0.0203 | 1116.2 | 22.66 | 2.3 |
| Bagging | 3.67 | 0.0068 | 1116.2 | 7.59 | 0.8 |
| **TOTAL** | **28** | **0.0517** | **1116.2** | **57.71** | **5.8** |
| **Adapted source data US Depart' of Labour 1899** | **Barley** | | | | |
| | **Av. hrs/30 US bu** | **Av. hrs/kg** | **Av. yield kg/ha** | **Hrs/ha** | **Man-days/ha** |
| Threshing | 15 | 0.0233 | 1166.4 | 27.18 | 2.7 |
| Winnowing | 12.75 | 0.0198 | 1166.4 | 23.09 | 2.3 |
| Bagging | 4.25 | 0.0066 | 1166.4 | 7.7 | 0.8 |
| **TOTAL** | **32** | **0.0497** | **1166.4** | **57.97** | **5.8** |
| Improvement ratio of threshing characteristics of modern free threshing cereals used in modern ethnographic studies over cereal varieties expected in the LBA (Russell 1988: 126) = | | | | | 2.5 |
| | | Uplifted Threshing and winnowing | | | 12.5 |
| | | Baggage | | | 0.8 |
| | | **Total man-days threshing, winnowing, and bagging** | | | **13.3** |

**Conversion factors**

| | |
|---|---|
| 1 man could thresh in one day kg | 300 |
| Assume working day in hrs | 10 |
| Density of dry barley kg/m2 | **609** |
| Density of dry wheat kg/m2 | **769** |
| Vol of one US bushell m3 | 0.0352 |
| Weight of one US bushell wheat kg | 27.07 |
| Weight of one US bushell barley kg | 21.44 |
| Average yield of wheat Cypriot conditions kg/ha | 714 |
| Average yield of wheat US 1866-1899 kg/ha | 1116.2 |
| Average yield of barley US 1866-1899 kg/ha | 1166.4 |

**Report 3.23c**

| **Manpower to mill wheat using Roman milling technology** | |
|---|---|
| Flour yield from milling wheat kg/hour | 7 |
| Number of operators | 2 |
| Total number of hours spent by two men to mill 1 kg wheat hours/kg | 0.29 |
| Average harvested wheat yield in Egypt kg/ha | 1156 |
| Average harvested wheat yield in Cypriot regions kg/ha | 714 |
| Total number of hours to mill wheat from 1 ha land in Egypt hours/ha | 331 |
| Total no.of hours to mill wheat from 1 ha land Cypriot regions hours/ha | 204.2 |
| **Tot no. of man-days to mill wheat from 1 ha land in Egypt** | **33** |
| **Total man-days to mill wheat from 1 ha land Cypriot regions** | **20.4** |

| | | |
|---|---|---|
| Number of utilised hrs worked per day by each operator | 10 | hrs |

**Report 3.24: Assumptions made to determine the man-years/ha required for the agricultural cycle**

| Classical evidence | | |
|---|---|---|
| Ploughing rate stated by Columella de r.r. 2.12 = | 3 | days/iugerum |
| Ploughing rate stated by Columella de r.r. 2.12 = | 0.33 | iugerum/day |
| Conversion rate 1 ieugerum = | 0.25 | ha |
| Ploughing rate stated by Columella de r.r. 2.12 = | 0.083 | ha/day |
| | 12.05 | days/ha |

**Report 3.24b**

Crossley and Kilger 1983 ethnographic evidence from Kenya

| | | |
|---|---|---|
| Ploughing rate using simple moulding board + two oxen | 25 | hours/ha |
| Assume utilised hrs per day | 8 | hours |
| Ploughing rate | 3.13 | days/ha |
| | 0.32 | ha/day |

| | | |
|---|---|---|
| 1 Assumptions for initial ploughing | | |
| Ploughing rate with pair of oxen in Egypt pulling a beladi plough = | 0.4 | feddan/day |
| Egyptian ploughing rate with pair of oxen = | 0.17 | ha/day |
| No. of days to plough one hectare = | 5.9 | man-days |
| Number of men required to plough and direct oxen = | 2 | |
| Number of man-days = | 11.8 | man-days/ha |
| 2 Assumptions for secondary tilth production | | |
| % time for tertiary ploughing compared with initial ploughing = | 50 | % |
| Ploughing at right angles to break up clods for Egypt = | 5.9 | man-days/ha |
| 3 Assumptions for tertiary ploughing | | |
| % time for tertiary ploughing compared with initial ploughing = | 38 | % |
| No. of days for second, ploughing to cover broadcast seeds in Egypt = | 4.5 | man-days/ha |
| 8 Assumptions for fourth ploughing and harrowing | | |
| % time for tertiary ploughing compared with initial ploughing = | 13 | % |
| No. of days for second, ploughing to cover broadcast seeds in Egypt = | 1.5 | man-days/ha |
| No. of days for harrowing = | 1.5 | man-days/ha |

**Report 3.24c: Harrowing estimates**

Columella, On Agriculture, II.10.27

| | hrs/iugera | man-days/ha |
|---|---|---|
| Sowing +Harrowing | 10 | 8.8 |
| Sowing experimental result | | 0.28 |
| Harrowing alone | | 8.52 |
| **Assume number of men per plough =** | 2 | |

**Report 3.24d**

| Columella's manp'r rates for Roman Italian estates | Wheat man days/ha | % of fallow land man-days |
|---|---|---|
| Breaking fallow land | 17.6 | N/A |
| 2nd ploughing | 8.8 | 50 |
| 3rd ploughing | 6.6 | 38 |
| 4th ploughing | 2.2 | 13 |

**Report 3.24a**

| Columella's manpower rates for Roman Italian estates | Wheat hrs/iugera | Wheat man days/ha | Barley hrs/iugera | Barley man days/ha |
|---|---|---|---|---|
| Breaking fallow land | 20 | 17.6 | | |
| 2nd ploughing | 10 | 8.8 | | |
| 3rd ploughing | 7.5 | 6.6 | | |
| Ridging and sowing | 2.5 | 2.2 | | |
| **Soil preparation** | **40** | **35.2** | **30** | **26.4** |

| Columella's manpower rates for Roman Italian estates | Wheat hrs/iugera | Wheat man days/ha | Barley hrs/iugera | Barley man days/ha |
|---|---|---|---|---|
| Soil preparation | 40 | 35.2 | 30 | 26.4 |
| Harrowing for tilth prodn. estimate | 10 | 8.8 | 10 | 8.8 |
| First hoeing | 20 | 17.6 | 15 | 13.2 |
| Second hoeing | 10 | 8.8 | 0 | 0 |
| Weeding estimate | 10 | 8.8 | 0 | 0 |
| Harvesting | 15 | 13.2 | 10 | 8.8 |
| **GRAND TOTAL** | **105** | **92.4** | **65** | **57.3** |
| **Rate used for conversion: 1 iugerum =** | | **0.2522** | **ha** | |
| **Assume utilised working day =** | | **9** | **hrs** | |
| **Assume number of men per plough =** | | **2** | **men** | |
| **% uplift over Columella's for Cypriot regions** | | **25** | **Ratio** | **1.25** |

| Activity | Wheat man-days/ha Egypt Fallow | Wheat man-days/ha Egypt Not fallow | Activity | Wheat man-days/ha Cypriot Fallow | Wheat man-days/ha Cypriot Not fallow |
|---|---|---|---|---|---|
| First ploughing | 17.6 | 11.8 | First ploughing | 22 | 11 |
| Second ploughing | 8.8 | 5.9 | Second ploughing | 11 | 8.3 |
| Third ploughing | 6.6 | 4.5 | Third ploughing | 8.3 | 2.8 |
| Fourth ploughing | 2.2 | 1.5 | Fourth ploughing | 2.8 | 2.8 |
| **Total** | **35.2** | **23.7** | **Total** | **44.1** | **24.9** |

| Activity | Barley man-days/ha Egypt Fallow | Barley man-days/ha Egypt Not fallow | Activity | Barley man-days/ha Cypriot Fallow | Barley man-days/ha Cypriot Not fallow |
|---|---|---|---|---|---|
| First ploughing | 17.6 | 11.8 | First ploughing | 22 | 11 |
| Second ploughing | 8.8 | 5.9 | Second ploughing | 11 | 8.3 |
| Third ploughing | 6.6 | 4.5 | Third ploughing | 8.3 | 2.8 |
| Fourth ploughing | 0 | 0 | Fourth ploughing | 2.8 | 0 |
| **Total** | **33** | **22.2** | **Total** | **44.1** | **22.1** |

| Activity | Pulses man-days/ha Egypt Fallow | Pulses man-days/ha Egypt Not fallow | Activity | Pulses man-days/ha Cypriot Fallow | Pulses man-days/ha Cypriot Not fallow |
|---|---|---|---|---|---|
| First ploughing | 17.6 | 11.8 | First ploughing | 22 | 11 |
| Second ploughing | 8.8 | 5.9 | Second ploughing | 11 | 8.3 |
| Third ploughing | 6.6 | 4.5 | Third ploughing | 8.3 | 2.8 |
| Fourth ploughing | 2.2 | 1.5 | Fourth ploughing | 2.8 | 2.8 |
| **Total** | **35.2** | **23.7** | **Total** | **44.1** | **24.9** |

**Report 3.25: Estimate of Egyptian man-days required to produce cereals and pulses on one ha of land per year when soil preparation carried out by ploughing**

**Report 3.25a**

| Cyprus | Land cultivated the previous year: Wheat man-days/ha | Barley man-days/ha | Pulses man-days/ha |
|---|---|---|---|
| First ploughing | 11 | 11 | 11 |
| Second ploughing | 8.3 | 8.3 | 8.3 |
| Tertiary ploughing | 2.8 | 2.8 | 2.8 |
| Fourth ploughing | 2.8 | - | 2.8 |
| **Soil Preparation Total** | **24.9** | **22.1** | **24.9** |
| Sowing estimate | 0.28 | 0.28 | 0.28 |
| Harrowing | 8.52 | 8.52 | 8.52 |
| Weeding using FAO 2006 guideline | 7 | 7 | 20.5 |
| Harvesting | 24.6 | 24.6 | 10 |
| Binding +Transportation of harvest | 24.1 | 24.1 | 24.1 |
| Threshing +winnowing | 12.5 | 12.5 | - |
| Shelling, drying and storing | - | - | 20 |
| Bagging of winnowed grain and pulses | 0.8 | 0.8 | 1 |
| Irrigation | 22 | 22 | 22 |
| **Total arable cultivation** | **124.7** | **121.9** | **131.3** |
| Milling | 20.4 | 20.4 | 20.4 |
| **GRAND TOTAL** | **145.1** | **142.3** | **151.7** |

| Egypt | Land cultivated the previous year: Wheat man-days/ha | Barley man-days/ha | Pulses man-days/ha |
|---|---|---|---|
| First ploughing | 11.8 | 11.8 | 11.8 |
| Second ploughing | 5.9 | 5.9 | 5.9 |
| Tertiary ploughing | 4.5 | 4.5 | 4.5 |
| Fourth ploughing | 1.5 | - | 1.5 |
| **Soil Preparation Total** | **23.7** | **22.2** | **23.7** |
| Sowing estimate | 0.28 | 0.28 | 0.28 |
| Harrowing | 8.52 | 8.52 | 8.52 |
| Weeding using FAO 2006 guideline | 7 | 7 | 20.5 |
| Harvesting | 24.6 | 24.6 | 10 |
| Binding +Transportation of harvest | 24 | 24 | 24 |
| Threshing +winnowing | 12.5 | 12.5 | - |
| Shelling, drying and storing | - | - | 20 |
| Bagging of winnowed grain and pulses | 0.8 | 0.8 | 1 |
| Irrigation | 86 | 86 | 86 |
| **Total arable cultivation** | **187.4** | **185.9** | **194** |
| Milling | 33 | 33 | 33 |
| **GRAND TOTAL** | **220.4** | **218.9** | **227** |

**Report 3.25b**

| Cyprus | Land left fallow in previous year: Wheat man-days/ha | Barley man-days/ha | Pulses man-days/ha |
|---|---|---|---|
| First ploughing | 22 | 22 | 22 |
| Second ploughing | 11 | 11 | 11 |
| Tertiary ploughing | 8.3 | 8.3 | 8.3 |
| Fourth ploughing | 2.8 | 2.8 | 2.8 |
| **Soil Preparation Total** | **44.1** | **44.1** | **44.1** |
| Sowing estimate | 0.28 | 0.28 | 0.28 |
| Harrowing | 8.52 | 8.52 | 8.52 |
| Weeding using FAO 2006 guideline | 7 | 7 | 20.5 |
| Harvesting | 24.6 | 24.6 | 10 |
| Binding +Transportation of harvest | 24.1 | 24.1 | 24.1 |
| Threshing +winnowing | 12.5 | 12.5 | - |
| Shelling, drying and storing | - | - | 20 |
| Bagging of winnowed grain and pulses | 0.8 | 0.8 | 1 |
| Irrigation | 22 | 22 | 22 |
| **Total arable cultivation** | **143.9** | **143.9** | **150.5** |
| Milling | 20.4 | 20.4 | 20.4 |
| **GRAND TOTAL** | **164.3** | **164.3** | **170.9** |

| Egypt | Land left fallow in previous year: Wheat man-days/ha | Barley man-days/ha | Pulses man-days/ha |
|---|---|---|---|
| First ploughing | 17.6 | 17.6 | 17.6 |
| Second ploughing | 8.8 | 8.8 | 8.8 |
| Tertiary ploughing | 6.6 | 6.6 | 6.6 |
| Fourth ploughing | 2.2 | - | 2.2 |
| **Soil Preparation Total** | **35.2** | **33** | **35.2** |
| Sowing estimate | 0.28 | 0.28 | 0.28 |
| Harrowing | 8.52 | 8.52 | 8.52 |
| Weeding using FAO 2006 guideline | 7 | 7 | 20.5 |
| Harvesting | 24.6 | 24.6 | 10 |
| Binding +Transportation of harvest | 24 | 24 | 24 |
| Threshing +winnowing | 12.5 | 12.5 | - |
| Shelling, drying and storing | - | - | 20 |
| Bagging of winnowed grain and pulses | 0.8 | 0.8 | 1 |
| Irrigation | 86 | 86 | 86 |
| **Total arable cultivation** | **198.9** | **196.7** | **205.5** |
| Milling | 33 | 33 | 33 |
| **GRAND TOTAL** | **231.9** | **229.7** | **238.5** |

**Report 3.25C**

| Region | Percentage of land in any given year left fallow: Marginal | Average | Best |
|---|---|---|---|
| **Egypt** | 50 | 10 | - |
| **Cypriot** | 50 | 33 | 25 |

**Report 3.25d: Assumptions broadcast sowing8**

| | |
|---|---|
| Distance seed can be thrown by sower either side in m | 1 |
| Assume width of field in m | 10 |
| Number of walking lengths to cover this area | 5 |
| Length of field if width is 10 m | 1000 |
| Total length m walked to sow one ha | 5000 |
| Assume speed of walker m/hr | 2000 |
| Time hrs to sow 1 ha | 2.5 |
| **Man-days/ha assuming a 9 hr utilised day** | **0.28** |

**Report 3.25e: Assumptions for weeding9**

| | |
|---|---|
| Area weeded per minute m2/min = | 2 |
| Time to weed one hectare mins = | 5000 |
| No. men required to weed one ha = | 9 |
| No. of weeding cycles = | 1 |
| Number of weeding cycles for pulses = | 2 |

**Report 3.25g: Harvesting of grain**

7 Assumptions Harvesting of grain and pulses using sickles (Halstead and Jones 1989: 47)

| | | |
|---|---|---|
| Reaping rate using sickles in Amorgos and Karpathos = | 1.5 | man-days/stremma |
| Reaping rate using sickles in Amorgos and Karpathos = | 15 | man-days/ha |

7 Assumptions Harvesting of pulses (Halstead and Jones 1989: 47)

| | | |
|---|---|---|
| Harvesting rate by uprooting in Amorgos and Karpathos = | 1 | man-days/stremma |
| Harvesting rate by uprooting in Amorgos and Karpathos = | 10 | man-days/ha |

**Report 3.25f: The relative reaping efficiencies of pre-historic hand sickles with stone inserts**

Ref Steensberg 1943: 23 and Korobkova 1981: 340

| | | |
|---|---|---|
| | 37.5 | 18.5 |
| | 33.3 | 18.5 |
| | 33.3 | 18.5 |
| | 27.8 | 18.5 |
| | 27.8 | 20 |
| | 26.7 | 23.8 |
| | 36.5 | 23.8 |
| | 23.8 | 24.6 |
| | 23.8 | 25.6 |
| | 20 | 26.7 |
| | 25.6 | 27 |
| | 27 | 27.8 |
| | 18.5 | 27.8 |
| | 18.5 | 31.6 |
| | 18.5 | 33.3 |
| | 18.5 | 33.3 |
| | 17.6 | 36.5 |
| | 17.6 | 37.5 |
| | 15.2 | 37.5 |
| **AVERAGE** | **24.6** | **26.9** |
| **± 95% Conf level** | **3.8** | **3.6** |
| **Average - 95% confidence level** | 20.8 | 23.3 |
| **Average + 95% confidence level** | 28.4 | 30.5 |
| **MAXIMUM** | 37.5 | 37.5 |
| **MINIMUM** | 15.2 | 18.5 |
| **STANDARD DEV** | 6.9 | 6.6 |
| **Population** | 19 | 19 |

**Report 3.26: Estimate of Cypriot regions man-days required to produce cereals and pulses on one ha of land per year when soil preparation carried out by hoeing**

| | | |
|---|---|---|
| **Haswell 1953: Appendices 2 and 6.** | | |
| Average man-days to hoe 1 ha | 24.7 | man-days/ha |
| **FAO 2006 study** | | |
| First hoeing on previously tilled soil | 14 | days |
| Second hoeing | 6.5 | days |
| **Total soil preparation** | **20.5** | **man-days/ha** |
| **Lewis 1951: 155, table 38.** | | |
| Clearance of vegetation | 4 | days |
| Man-days to hoe 1 ha, hoed four times | 60 | days |
| **Total soil preparation** | **64** | **man-days/ha** |

| Cyprus | Wheat man-days/ha | Barley man-days/ha | Pulses man-days/ha |
|---|---|---|---|
| Hoeing | 100.1 | 100.1 | 100.1 |
| Sowing estimate | 0.28 | 0.28 | 0.28 |
| Harrowing | 8.52 | 8.52 | 8.52 |
| Weeding estimate | 25.3 | 25.3 | 32.9 |
| Harvesting | 24.6 | 24.6 | 10 |
| Threshing +winnowing | 12.5 | 12.5 | - |
| Shelling, drying and storing | - | - | 20 |
| Bagging of winnowed grain and pulses | 0.8 | 0.8 | 1 |
| Irrigation | 22 | 22 | 22 |
| **Total arable cultivation** | **194.1** | **194.1** | **194.8** |
| Milling | 20.4 | 20.4 | 20.4 |
| **GRAND TOTAL** | **214.5** | **214.5** | **215.2** |

**Ratio uplift to compensate for modern hoes =** 1.3

**Ratio for decreasing Egyptian workload to take into account easier hoeing conditions** 0.8

Enter 1 for higher Egyptian hoeing rate | 1

| Activity | Egypt | Cypriot | | Egypt modified |
|---|---|---|---|---|
| Clearance + 1st hoeing (based on 1969 FO study) | 26 | 34.5 | man-days/ha | 21 |
| Interpolated | 17.5 | 22 | man-days/ha | 14 |
| Third dig (based on 2006 FAO study) | 14 | 14 | man-days/ha | 14 |
| Fourth dig (based on 2006 FAO study) | 6.5 | 6.5 | man-days/ha | 6.5 |
| **Total soil preparation** | **64** | **77** | **man-days/ha** | **55.5** |
| **Uplifted to compensate data based on steel hoes** | **83.2** | **100.1** | | |

| Egypt | Wheat man-days/ha | Barley man-days/ha | Pulses man-days/ha |
|---|---|---|---|
| Hoeing | 83.2 | 83.2 | 83.2 |
| Sowing estimate | 0.28 | 0.28 | 0.28 |
| Harrowing | 8.52 | 8.52 | 8.52 |
| Weeding estimate | 18.5 | 18.5 | 22.2 |
| Harvesting | 24.6 | 24.6 | 10 |
| Threshing +winnowing | 12.5 | 12.5 | - |
| Shelling, drying and storing | - | - | 20 |
| Bagging of winnowed grain and pulses | 0.8 | 0.8 | 1 |
| Irrigation | 86 | 86 | 86 |
| **Total arable cultivation** | **234.4** | **234.4** | **231.2** |
| Milling | 33 | 33 | 33 |
| **GRAND TOTAL** | **267.4** | **267.4** | **264.2** |

**Report 3.26a: Weeding assumptions used in the model for the case of hoeing**

| | | | |
|---|---|---|---|
| Weeding using hoes for cereals | **Egypt** | **Cypriot** | |
| First weeding cycle (adapted from FAO 2006 study) | 12.6 | 16.8 | man-days/ha |
| Second weeding cycle (adapted from FAO 2006 study) | 5.9 | 8.5 | man-days/ha |
| **Total soil preparation** | **18.5** | **25.3** | **man-days/ha** |
| Weeding using hoes for pulses uplift over cereals | **Egypt** | **Cypriot** | |
| First weeding cycle (adapted from FAO 2006 study) | 15.1 | 21.8 | man-days/ha |
| Second weeding cycle (adapted from FAO 2006 study) | 7.1 | 11.1 | man-days/ha |
| **Total soil preparation** | **22.2** | **32.9** | **man-days/ha** |
| **Ratios used to adapt FAO 2006 Weeding Study** | **Egypt** | **Cypriot** | |
| Ratio of FAO 2006 weeding study for soil conditions | 0.9 | 1.2 | |
| Ratio of the FAO 2006 weeding study for pulses | 1.2 | 1.3 | |

**Report 3.26b: Baslers ethnographic evidence for improvements in yield of lentils due to weeding**

| Sowing rate of lentils (kg/ha) | Yield from lentil beds left unweeded (kg/ha) | Yield following weeding in the growing season (kg/ha) | Percentage improvement in yield |
|---|---|---|---|
| 100 | 60 | 642 | 1070 |
| 150 | 90 | 547 | 608 |
| 200 | 62 | 441 | 711 |

**Report 3.26c: Sensitivity test on Egyptian assumption for hoeing rate**

| | |
|---|---|
| Total agrarian manpower assuming hoeing rate 64 man-days/ha | 37,195 |
| Total agrarian manpower assuming hoeing rate 55.5 man-days/ha | 36,192 |
| **Difference** | **1,003** |
| **Percentage difference** | **2.7** |

**Report 3.27: Assumptions made for the man power required for oil production**

**Report 3.27a: Man-years required to convert olives to oil**

| | | |
|---|---|---|
| 1 Estimated olive oil production at the 7th century B.C. production centre at Tell Miqne = | 230 | tonnes |
| Estimated oilve oil production at the 7th century B.C. production centre at Tell Miqne = | 208,617 | kgs |
| Area under cultivation at Tell Miqne (using average from Report 3.12) = | 767 | ha |
| Area required for olive production = | 7,654 | ha |
| Number of olive oil productions centres required using Iron Age technology = | 10 | |
| Assume the number of workers working at each olive oil production centre = | 8 | |
| Number of days working/year at each olive oil production centres = | 180 | days |
| Total workload = | 14,400 | man-days/ha |
| Utilisation factor = | 0.8 | |
| Total man-days required at production centres/ha = | 2.4 | man-days/ha |
| 1 Agricultural effort = | 125 | man-days/ha |
| Combined production and agricultural effort = | **127.4** | man-days/ha |

**Report 3.27b: Man-years to convert sesame seed to oil**

| | | |
|---|---|---|
| 3 Farming man/years/ha to produce sesame seed production by Peloponnese farming in 1959 = | 77 | man-days/ha |
| Less irrigation within Peloponese farming man years/ha taken (see irrigation assumptions Report 3.21) = | -22 | man-days/ha |
| Assume irrigation man-years requirement to irrigate sesame crops/ha is the same as cereals (see Report 19, cell I25) = | 86 | man-days/ha |
| Assume transport manpower the same as cereals = | 33 | man-days/ha |
| | **174** | man-days/ha |
| Assume sesame processsing time to produce oil from seed is the same ratio as that for olive oil from olives = | 2.4 | man-days/ha |
| Combined production and agricultural effort = | **176.4** | man-days/ha |

**References**

[1] Serpico 2004: 104 and http://www.aiar.org/docs/EkronSummary.pdf.
[2] Davis 1973, Appendix 6
[3] Pepelasis and Yotopoulos 1962: 180, table A-10

# SURPLUS CALCULATION

**Report 3.28a: Man-years taken to feed 100000 persons/yr with the population remaining healthy for Cyprus**

**Case A: Land prepared by ploughing using oxen**

| Food type | Total area ha required/ yr to feed 100000 people | Man days/ha/yr Minimum | Total Man-days | Total Man-years |
|---|---|---|---|---|
| Barley | 15,905 | 164.3 | 2,613,192 | 7,159 |
| Emmer wheat | 18,697 | 164.3 | 3,071,917 | 8,416 |
| [1] Pulses (chick peas) | 26,549 | 170.9 | 4,537,224 | 12,431 |
| TOTAL ARABLE LAND | 61,151 | | 10,222,333 | 28,006 |
| [2] Olive production | 7,654 | 127.4 | 975,120 | 2,672 |
| [3] Wine production | 537 | 148.00 | 79,476 | 218 |
| TOTAL CULTIVATED LAND | 69,342 | | 11,276,929 | 30,896 |
| Mutton | N/A | | | 1,961 |
| Transport crops to tax centre | N/A | | | 11 |
| Fodder | 10,018 | | 181,037 | 496 |
| | | Total man-years | 11,457,966 | 33,364 |
| Grand total million ha | 79,360 | Utilized arable man-years | | 39,538 |
| | | Scheduling/time/skill/gender loss factor | | 4,400 |
| | | TOTAL AGRARIAN man-years | | 43,938 |
| | | Non-productive age groups | | 30,860 |
| | | SURPLUS man-years | | 25,202 |
| | | Population sample | | 100,000 |

**Case B: Land prepared using hoes**

| Food type | Total area ha required/ yr to feed 100000 people | Man days/ha/yr Minimum | Total Man-days | Total Man-years |
|---|---|---|---|---|
| Barley | 15,905 | 214.5 | 3,411,623 | 9,347 |
| Emmer wheat | 18,697 | 214.5 | 4,010,507 | 10,988 |
| [1] Pulses (chick peas) | 26,549 | 215.2 | 5,713,345 | 15,653 |
| TOTAL ARABLE LAND | 61,151 | | 13,135,475 | 35,988 |
| [2] Olive oil production | 7,654 | 127.4 | 975,120 | 2,672 |
| [3] Wine production | 537 | 148.00 | 79,476 | 218 |
| TOTAL ARABLE LAND | 69,342 | | 14,190,071 | 38,878 |
| [4] Mutton | N/A | | | 1,961 |
| Transport crops to tax centre | N/A | | | 11 |
| Fodder | 2,147 | | 181,037 | 6 |
| | | Total man-years | 14,371,108 | 40,856 |
| Grand total million ha | 71,489 | Utilized arable man-years | | 48,417 |
| | | Scheduling/time/skill/gender loss factor | | 4,400 |
| | | TOTAL AGRARIAN man-years | | 52,817 |
| | | Non-productive age groups | | 30,860 |
| | | SURPLUS man-years | | 16,323 |
| | | Population sample | | 100,000 |

**Report 3.28b: Time lost in scheduling workload**

| **Assumptions Egypt** | % |
|---|---|
| Scheduling/time/skill/gender time loss factor | 10 |
| Average arable man-years | 32,676 |
| Uplift required for time loss | 3268 |
| Round down uplift to nearest 10 | 3270 |

| | |
|---|---|
| Tot man-years assuming 50/50% ploughing/hoeing split | **32,676** |

| **Assumptions Cypriot** | % |
|---|---|
| Scheduling/time/skill/gender time loss factor | 10 |
| Average arable man-years | 43,978 |
| Uplift required for time loss | 4398 |
| Round down uplift to nearest 10 | 4400 |

| | |
|---|---|
| Tot man-years assuming 50/50% ploughing/hoeing split | **43,978** |

Days available for farming after taking out festivals, rain, sickness = 308 days

[4] See Mutton assumptions Report 15, No of shepherds to provide protein requirements for 100000 people = 1961 man-years


**References**

1 Pepelais and Yotopoulos 1962: 180 Table A-10.

2 Gallant 1991:76, Pepelais and Yotopoulos 1962: 180, Table A10.

3 Davis 1973, Appendix 6

**Report 3.29: Man-years taken to feed 100000 persons/yr with the population remaining healthy for Egypt**

| A | B | C | D | E | F |
|---|---|---|---|---|---|
| | | **Case A: Land prepared by ploughing using oxen** | | | |
| **Food type** | | **Total area ha required/ yr to feed 100000 people** | **Man days/ha/yr Minimum** | **Total Man-days** | **Total Man-years** |
| Barley | | 19,854 | 229.7 | 4,560,464 | 12,494 |
| Emmer wheat | | 5,790 | 231.9 | 1,342,701 | 3,679 |
| 1 Pulses (chick peas) | | 12,087 | 238.5 | 2,882,750 | 7,898 |
| TOTAL ARABLE LAND | | 37,731 | | 8,785,915 | 24,071 |
| 2 Sesame oil production | | 103 | 176.4 | 18,169 | 50 |
| 3 Wine production | | N/A | | | |
| TOTAL CULTIVATED LAND | | 37,834 | Total arable m-yrs | 8,804,084 | 24,121 |
| Mutton | | N/A | | | 490 |
| Transport crops to tax centre | | N/A | | | 14 |
| Fodder | | 21,825 | | 876,561 | 2,402 |
| | | | | 9,680,645 | 27,027 |
| Grand total million ha | | 59,659 | Utilized arable man-years | | 32,028 |
| | | | Scheduling/time/skill/gender time loss | | 3,270 |
| | | | Inundation management | | 1,000 |
| | | | TOTAL AGRARIAN man-years | | 36,298 |
| | | | Non-productive age groups | | 30,860 |
| | | | SURPLUS man-years | | 32,842 |
| | | | Population sample | | 100,000 |

| G | H | I | J | K | L |
|---|---|---|---|---|---|
| | | **Case B: Land prepared using hoes** | | | |
| **Food type** | | **Total area ha required/ yr to feed 100000 people** | **Man days/ha/yr Minimum** | **Total Man-days** | **Total Man-years** |
| Barley | | 19,854 | 267.4 | 5,308,960 | 14,545 |
| Emmer wheat | | 5,790 | 267.4 | 1,548,246 | 4,242 |
| 5 Pulses (chick peas) | | 12,087 | 264.2 | 3,193,385 | 8,749 |
| TOTAL ARABLE LAND | | 37,731 | | 10,050,591 | 27,536 |
| 2 Sesame oil production | | 103 | 176.4 | 18,169 | 50 |
| 3 Wine production | | N/A | | | |
| TOTAL ARABLE LAND | | 37,834 | Total arable m-yrs | 10,068,760 | 27,586 |
| 5 Mutton | | N/A | | | 490 |
| Transport crops to tax centre | | N/A | | | 14 |
| Fodder | | 2,147 | | 876,561 | 29 |
| | | | | 10,945,321 | 28,119 |
| Grand total million ha | | 39,981 | Utilized arable man-years | | 33,323 |
| | | | Scheduling/time/skill/gender time loss | | 3,270 |
| | | | Inundation management | | 1,000 |
| | | | TOTAL AGRARIAN man-years | | 37,593 |
| | | | Non-productive age groups | | 30,860 |
| | | | SURPLUS man-years | | 31,547 |
| | | | Population sample | | 100,000 |

**References**

1 Pepelais and Yotopoulos 1962: 180 Table A-10.

2 Gallant 1991:76, Pepelais and Yotopoulos 1962: 180, Table A10.

3 Pepelais and Yotopoulos 1962, 180 Table A-10.

4 Serpico 2004: 104.

ee Mutton assumptions Report 15, No of shepherds to provide protein requirements for 100000 people

**Report 3.29a: Analysis of the number of days worked per year. Reference Quirke 2003b.**

| | Festival days | | | | | | Total |
|---|---|---|---|---|---|---|---|
| Months | 1 | 2 | 3 | 4 | 5 | 6 | |
| No. of festivals | 7 | 11 | 1 | 5 | 5 | 3 | 32 |
| Months | 7 | 8 | 9 | 10 | 11 | 12 | |
| No. of festivals | 6 | 2 | 6 | 2 | 2 | 3 | 21 |
| | | | | | | **12 months total** | **53** |

| | |
|---|---|
| % of festivals celebrated by farmers and days therefore lost to farming = | 10 |
| Rounded up no. of days lost to festivals = | 6 |
| No. of days lost to sickness = | 15 |
| **Days available for farming after taking out sickness and festivals =** | **344** |
| **Egypt** | |
| Days lost for day off every 10 days | 36 |
| Net days available for farming | **308** |
| **Cypriot/Cypriot** | |
| Days lost to the bad weather/sickness | 36 |
| Net days available for farming | **308** |

| | |
|---|---|
| Percentage scheduling/time/skill/gender time loss | 10 |
| Percentage days lost for festivals, sickness, etc | 16 |
| Total percentage time lost | **26** |
| Percentage utilisation | **74** |
| Example workload man-days | 200 |
| Individuals required | 252 |

Report 3.30: Tabulated summary results for Cypriot regions for areas under cultivation and farming man-years of effort

| | CROP | Ploughing | Hoeing | Ploughing | Hoeing | | Ploughing | Hoeing |
|---|---|---|---|---|---|---|---|---|
| | | Area ha | Area ha | man days/ha | | | man-years | man-years |
| **Consumerable cereal and pulses** | Barley | 12,573 | 12,573 | 164.3 | 214.5 | | 5,660 | 7,389 |
| | Wheat | 14,780 | 14,780 | 164.3 | 214.5 | | 6,653 | 8,686 |
| | Pulses | 20,987 | 20,987 | 170.9 | 215.2 | | 9,827 | 12,374 |
| | | **48,340** | **48,340** | | | | **22,140** | **28,449** |
| **Consumerable oil and wine** | Olive oil | 6,958 | 6,958 | 127.4 | 127.4 | | 2,429 | 2,429 |
| | Sesame oil | 0 | 0 | 0 | 0 | | 0 | 0 |
| | Wine | 413 | 413 | 148 | 148 | | 167 | 167 |
| | | **7,371** | **7,371** | | | | **2,596** | **2,596** |
| **Wastage** | Barley | 1,886 | 1,886 | 164.3 | 214.5 | | 849 | 1,108 |
| | Wheat | 2,217 | 2,217 | 164.3 | 214.5 | | 998 | 1,303 |
| | Pulses | 3,148 | 3,148 | 170.9 | 215.2 | | 1,474 | 1,856 |
| | Sesame oil | 0 | 0 | 0 | 0 | | 0 | 0 |
| | Olive Oil | 696 | 696 | 127.4 | 127.4 | | 243 | 243 |
| | Wine | 124 | 124 | 148 | 148 | | 50 | 50 |
| | | **8,071** | **8,071** | | | | **3,614** | **4,560** |
| **Seed corn** | Barley | 1,446 | 1,446 | 164.3 | 214.5 | | 651 | 850 |
| | Wheat | 1,700 | 1,700 | 164.3 | 214.5 | | 765 | 999 |
| | Pulses | 2,414 | 2,414 | 170.9 | 215.2 | | 1,130 | 1,423 |
| | Sesame | 0 | 0 | 0 | 0 | | 0 | 0 |
| | | **5,560** | **5,560** | | | | **2,546** | **3,272** |
| **Fodder** | Alfalfa | 10,018 | 1,073 | | | | 496 | 6 |
| | | 0 | 0 | | | | 0 | 0 |
| | | **10,018** | **1,073** | | | | **496** | **6** |
| **Taxation** | Barley | 0 | 0 | 164.3 | 214.5 | | 0 | 0 |
| | Wheat | 0 | 0 | 164.3 | 214.5 | | 0 | 0 |
| | Olive Oil | 0 | 0 | 127.4 | 127.4 | | 0 | 0 |
| | Sesame oil | 0 | 0 | 0 | 0 | | 0 | 0 |
| | Wine | **0** | **0** | 148 | 148 | | **0** | **0** |
| | Total area of production ha | **79,360** | **70,415** | | | **Total arable man-years** | **31,392** | **38,883** |
| **Total Harvest by crop** | | | | | | **Crop** | **Man-years/100,000 population** | |
| **Total Harvest by crop** | Barley | 15,905 | 15,905 | 164.3 | 214.5 | **Barley** | 7,159 | 9,347 |
| | Wheat | 18,697 | 18,697 | 164.3 | 214.5 | **Wheat** | 8,416 | 10,988 |
| | Pulses | 26,549 | 26,549 | 170.9 | 215.2 | **Pulses** | 12,431 | 15,653 |
| | Olive Oil | 7,654 | 7,654 | 127.4 | 127.4 | **Olive Oil** | 2,672 | 2,672 |
| | Sesame oil | 0 | 0 | 0 | 0 | **Sesame oil** | 0 | 0 |
| | Wine | 537 | 537 | 148 | 148 | **Wine** | 218 | 218 |
| | Fodder | 10,018 | 1,073 | | | **Alfalfa fodder** | 496 | 6 |
| | | **79,360** | **70,415** | | | **Total arable man-years** | **31,392** | **38,884** |
| | | | **Total agrarian utilised man-years** | **43,938** | **52,817** | Mutton + transport | 1,972 | 1,972 |
| | | | Non-productive age groups | 30,860 | 30,860 | **Total man-years** | **33,364** | **40,856** |
| | | | **Surplus** | 25,202 | 16,323 | Utilised total man-years worked | **39,538** | **48,417** |
| | | | **Population sample** | **100,000** | **100,000** | Scheduling/time/skill/gender time loss | 4,400 | 4,400 |
| | | | **Tot man-yrs assuming 50/50% ploughing/hoeing** | | **48,378** | **Total agrarian utilised man-years** | **43,938** | **52,817** |

| Report 3.31: Egypt - areas under cultivation and farming man-years of effort | CROP | Ploughing Area ha | Hoeing Area ha | | Ploughing man days/ha | Hoeing man days/ha | | Ploughing man-years | Hoeing man-years |
|---|---|---|---|---|---|---|---|---|---|
| Consumerable cereal and pulses | Barley | 15,459 | 15,459 | | 229.7 | 267.4 | | 9,729 | 11,325 |
| | Wheat | 4,509 | 4,509 | | 231.9 | 267.4 | | 2,865 | 3,303 |
| | Pulses | 9,411 | 9,411 | | 238.5 | 264.2 | | 6,149 | 6,812 |
| | | 29,379 | 29,379 | | | | | 18,743 | 21,440 |
| Consumerable oil and wine | Olive oil | 0 | 0 | | 0 | 0 | | 0 | 0 |
| | Sesame oil | 103 | 103 | | 176.4 | 176.4 | | 50 | 50 |
| | Wine | 0 | 0 | | 0 | 0 | | 0 | 0 |
| | | 103 | 103 | | | | | 50 | 50 |
| Wastage | Barley | 2,590 | 2,590 | | 229.7 | 267.4 | | 1,630 | 1,897 |
| | Wheat | 755 | 755 | | 231.9 | 267.4 | | 480 | 553 |
| | Pulses | 1,577 | 1,577 | | 238.5 | 264.2 | | 1,030 | 1,141 |
| | Sesame oil | 0 | 0 | | 176.4 | 176.4 | | 0 | 0 |
| | Olive Oil | 0 | 0 | | 0 | 0 | | 0 | 0 |
| | Wine | 0 | 0 | | 0 | 0 | | 0 | 0 |
| | | 4,922 | 4,922 | | | | | 3,140 | 3,591 |
| Seed corn | Barley | 1,805 | 1,805 | | 229.7 | 267.4 | | 1,136 | 1,322 |
| | Wheat | 526 | 526 | | 231.9 | 267.4 | | 334 | 385 |
| | Pulses | 1,099 | 1,099 | | 238.5 | 264.2 | | 718 | 795 |
| | Sesame | 0 | 0 | | 176.4 | 176.4 | | 0 | 0 |
| | | 3,430 | 3,430 | | | | | 2,188 | 2,502 |
| Fodder | Alfalfa | 21,825 | 2,147 | | | | | 2,402 | 29 |
| | | 0 | 0 | | | | | 0 | 0 |
| | | 21,825 | 2,147 | | | | | 2,402 | 29 |
| Taxation | Barley | 0 | 0 | | 229.7 | 267.4 | | 0 | 0 |
| | Wheat | 0 | 0 | | 231.9 | 267.4 | | 0 | 0 |
| | Olive Oil | 0 | 0 | | 0 | 0 | | 0 | 0 |
| | Sesame oil | 0 | 0 | | 176.4 | 176.4 | | 0 | 0 |
| | Wine | 0 | 0 | | 0 | 0 | | 0 | 0 |
| **Total Harvest by crop** | | 59,659 | 39,981 | | | | **Total arable man-years** | 26,523 | 27,612 |
| **Total Harvest by crop** | Barley | 19,854 | 19,854 | | 229.7 | 267.4 | **Barley** | 12,494 | 14,545 |
| | Wheat | 5,790 | 5,790 | | 231.9 | 267.4 | **Wheat** | 3,679 | 4,242 |
| | Pulses | 12,087 | 12,087 | | 238.5 | 264.2 | **Pulses** | 7,898 | 8,749 |
| | Olive Oil | 0 | 0 | | 0 | 0 | **Olive Oil** | 0 | 0 |
| | Sesame oil | 103 | 103 | | 176.4 | 176.4 | **Sesame oil** | 50 | 50 |
| | Wine | 0 | 0 | | 0 | 0 | **Wine** | 0 | 0 |
| | Fodder | 21,825 | 2,147 | 100 | | | **Alfalfa fodder** | 2,402 | 29 |
| Report 3.31a | | 59,659 | 39,981 | | | | **Total arable man-years** | 26,523 | 27,615 |

| **Man-years required to grow one sack of barley in Egypt** | |
|---|---|
| Direct cost of barley 50/50 pl'ng/ho'g case | 13,520 |
| Tot arable direct m/p 50/50 case | 27,069 |
| Tot arable direct m/p+ overhead 50/50 case | 36,946 |
| Overhead | 9,877 |
| Proportion of overhead allocated to barley | 4933 |
| Real cost of barley production to feed 100,000 people | 18,453 |

| | | |
|---|---|---|
| Tot man-years including overhead assuming 50/50% ploughing/hoeing | 18,453 | man-years |
| Weight of barley to feed 100,000 people | 14,640,060 | kg |
| Volume of barley to feed 100,000 people with density of 609 kg/m3 | 24040 | m3 |
| Weight of one sack barley (77 litres=0.077 m3) | 46.9 | kg |
| Man-years assuming 50/50% ploughing/hoeing to produce one sack barley | 0.059 | man-years |
| Man-year to make 2 deben of copper at Timna | 0.1506 | man-years |
| Ratio | 2.55 | |
| Man-year to make 2 deben of copper in Cyprus | 0.0788 | man-years |
| Ratio | 1.04 | |

| | Ploughing | Hoeing |
|---|---|---|
| Mutton + transport | 504 | 504 |
| **Total man-years** | 27,027 | 28,119 |
| Tot. arable man-years re days worked | 32,028 | 33,323 |
| Scheduling/time/skill/gender time loss | 3,270 | 3,270 |
| Inundation management | 1,000 | 1,000 |
| **Total agrarian man-year** | 36,298 | 37,593 |
| Non-productive age groups | 30,860 | 30,860 |
| **Surplus** | 32,842 | 31,547 |
| **Population sample** | 100,000 | 100,000 |

**Report 3.31b**

| Man-years required to grow one sack of barley in Cyprus | |
|---|---|
| Direct cost of barley 50/50 pl'ng/ho'g case | 8,253 |
| Tot arable direct m/p 50/50 case | 35,138 |
| Tot arable direct m/p+ overhead 50/50 case | 48,378 |
| Overhead | 13,240 |
| Proportion of overhead allocated to barley | 3110 |
| Real cost of barley production to feed 100,000 people | 11,363 |

| | |
|---|---|
| Tot man-years including overhead assuming 50/50% ploughing/hoeing | 11,363 |
| Weight of barley to feed 100,000 people | 7,045,783 |
| Volume of barley to feed 100,000 people with density of 609 kg/m3 | 11569 |
| Weight of one sack barley (77 litres=0.077 m3) | 46.9 |
| Man-years assuming 50/50% ploughing/hoeing to produce one sack barley | 0.076 |
| Man-year to make 2 deben of copper in Cyprus | 0.0788 |
| Ratio | 1.04 |
| Relative costs Timna to Cyprus | 2.5 |

**Report 3.32: Tabulated summary results Cypriot regions and Egypt**

**Report 3.32A**

| Cypriot and North Eastern Med. regions | | | |
|---|---|---|---|
| Category | Area ha | Ploughing | Hoeing |
| | | Area ha | Area ha |
| Consumerable cereals and pulses | 48,340 | 48,340 | 48,340 |
| Consumerable oil and wine | 7,371 | 7,371 | 7,371 |
| Wastage | 8,071 | 8,071 | 8,071 |
| Afalfa fodder | 5,546 | 10,018 | 1,073 |
| Seed corn | 5,560 | 5,560 | 5,560 |
| **TOTAL ha** | **74,888** | **79,360** | **70,415** |

**Summary fodder**

| Region | Percentage fodder | |
|---|---|---|
| | Ploughing | Hoeing |
| Cypriot | 12.6 | 1.5 |
| Egypt | 36.6 | 5.4 |

**Report 3.32B**

| Egypt | | |
|---|---|---|
| Category | Ploughing | Hoeing |
| | Area ha | Area ha |
| Consumerable cereals and pulses | 29,379 | 29,379 |
| Consumerable oil and wine | 103 | 103 |
| Wastage | 4,922 | 4,922 |
| Afalfa fodder | 21,825 | 2,147 |
| Seed corn | 3,430 | 3,430 |
| Taxation | 0 | 0 |
| **TOTAL ha** | **59,659** | **39,981** |

Area (ha) required producing sufficient seed corn for next years harvest to support 100,000 people for a Cypriot ratio of 1:6 and 1:10 for Egypt

| Crop | Cypriot regions | | Egypt | |
|---|---|---|---|---|
| | Ploughing | Hoeing | Ploughing | Hoeing |
| | Area ha | Area ha | Area ha | Area ha |
| Barley | 1,446 | 1,446 | 1,805 | 1,805 |
| Emmer wheat | 1,700 | 1,700 | 526 | 526 |
| Pulses | 2,414 | 2,414 | 1,099 | 1,099 |
| **Total** | **5,560** | **5,560** | **3,430** | **3,430** |

**Report 3.32D**

| Cypriot and North Eastern Med. regions | | |
|---|---|---|
| Category | Ploughing | Hoeing |
| | man-years | man-years |
| Consumerable cereals and pulses | 22,140 | 28,449 |
| Consumerable oil and wine | 2,596 | 2,596 |
| Wastage | 3,614 | 4,560 |
| Afalfa fodder | 496 | 6 |
| Seed corn | 2,546 | 3,272 |
| **Total arable man-years** | **31,392** | **38,883** |
| **Mutton + transport** | 1,972 | 1,972 |
| **Total man-years** | **33,364** | **40,855** |
| **Total arable man-years re days worked** | **39,538** | **48,416** |
| Scheduling/time/skill/gender time loss | 4,400 | 4,400 |
| **Total agrarian man-years** | **43,938** | **52,816** |
| Non productive age groups | 30,860 | 30,860 |
| **Surplus** | **25,202** | **16,324** |
| **Population sample** | 100,000 | 100,000 |

| | |
|---|---|
| **Tot man-years assuming 50/50% ploughing/hoeing** | **48,377** |
| **Rounded total man-years assuming 50/50% split** | **48,380** |

| Egypt | | |
|---|---|---|
| Category | Ploughing | Hoeing |
| | man-years | man-years |
| Consumerable cereals and pulses | 18,743 | 21,440 |
| Consumerable oil and wine | 50 | 50 |
| Wastage | 3,140 | 3,591 |
| Afalfa fodder | 2,402 | 29 |
| Seed corn | 2,188 | 2,502 |
| **Total arable man-years** | **26,523** | **27,612** |
| **Mutton + transport** | 504 | 504 |
| **Total man-years** | **27,027** | **28,116** |
| **Total arable man-years re days worked** | **32,028** | **33,320** |
| Scheduling/time/skill/gender time loss | 3,270 | 3,270 |
| Innundation mangement | 1,000 | 1,000 |
| **Total agrarian man-years** | **36,298** | **37,590** |
| Non productive age groups | 30,860 | 30,860 |
| **Surplus** | **32,842** | **31,550** |
| **Population sample** | 100,000 | 100,000 |

**Report 3.33: Analysis of Breasted and Pritchards assumptions for Tuthmosis' grain booty from his first Asiatic campaign**

**Textual evidence**

| | | |
|---|---|---|
| Text line 21= | 208,200 + [+x] | units of volume |

**Equivalence estimates**

| | | | | | |
|---|---|---|---|---|---|
| Breasted II, 189 | 112632 | Imperial Bushels | Authors estimate= | 109345 | Imperial Bushels |
| Pritchard 1955: 238 footnote 47 | 450000 | Imperial Bushels | | | |

**This would weigh**

| | | | | |
|---|---|---|---|---|
| Breasted Wheat | 3153696 | kg | 3.154 | million kg |
| Pritchard Wheat | 12600000 | kg | 12.6 | million kg |
| Breasted barley | 2500430.4 | kg | 2.5 | million kg |
| Pritchard barley | 9990000 | kg | 9.99 | million kg |

**This would provide to the diet these energy levels of:**

| | | |
|---|---|---|
| Breasted Wheat | 10470 | million kcals |
| Pritchard Wheat | 41832 | million kcals |
| Breasted barley | 8301 | million kcals |
| Pritchard barley | 33167 | million kcals |

**From table 2.9 grain provides these energy levels:**

| | | |
|---|---|---|
| Energy supplied by grain = | 64807 | million kcals/yr/100000 population |
| Energy supplied by grain = | 0.648 | million kcals/yr/man |

**This could sustain the following no. of men:**

| | | |
|---|---|---|
| Breasted Wheat | 16157 | men |
| Pritchard Wheat | 64556 | men |
| Breasted barley | 12810 | men |
| Pritchard barley | 51184 | men |

**Conversion rates**

| | | | | |
|---|---|---|---|---|
| 1 bushell = | 36.4 | litres | imperial | |
| 1 bushell = | 35.2 | litres | US | |
| 1 bushell = | 0.0364 | m3 | imperial | |
| 1 bushell = | 0.0352 | m3 | US | |
| 1 bushell = | 28 | kg | imperial | Wheat |
| 1 bushell = | 27.1 | kg | US | Wheat |
| 1 bushell = | 22.2 | kg | imperial | Barley |
| 1 bushell = | 21.4 | kg | US | Barley |
| Caloric value wheat = | 3320 | kcals/kg | | |
| Caloric value barley = | 3320 | kcals/kg | | |

**Summary**

| Evidence source | Wheat | | Barley | |
|---|---|---|---|---|
| | Breasted | Wilson | Breasted | Wilson |
| Vol. of grain inperial bushels | 112,632 | 450,000 | 112,632 | 450,000 |
| Wt of grain million kg | 3.154 | 12.6 | 2.5 | 9.99 |
| No. of men that could be fed | 16,157 | 64,556 | 12,810 | 51,184 |

Report 3.34a: Tabulated Cypriot region's yield rates for barley, wheat and pulses taken from Reports 10-13, analysis assumes marginal, average and best land is represented by 95% conf. levels

| All Data | | | | | | Less maximum and minimum outliers | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Pulses | | | | | | Pulses | | | |
| Barley kg/ha | Wheat kg/ha | Beans kg/ha | Lentils kg/ha | Total Pulses kg/ha | Greece only Total pulses kg/ha | Barley kg/ha | Wheat kg/ha | Beans kg/ha | Lentils kg/ha | Combined pulses kg/ha | Greece only total pulses kg/ha |
| 695.5 | 642.7 | 743.5 | 537.2 | 650.9 | 650.9 | 695.5 | 642.7 | 650.9 | 537.2 | 650.9 | 650.9 |
| 666.9 | 666.4 | 650.9 | 498.1 | 542.7 | 542.7 | 666.9 | 666.4 | 542.7 | 498.1 | 542.7 | 542.7 |
| 733.4 | 624.5 | 542.7 | 410.9 | 657.2 | 657.2 | 733.4 | 624.5 | 657.2 | 410.9 | 657.2 | 657.2 |
| 598.7 | 470 | 657.2 | 539.9 | 630.9 | 630.9 | 598.7 | 470 | 630.9 | 539.9 | 630.9 | 630.9 |
| 793.7 | 629.1 | 630.9 | 611.2 | 638.4 | 638.4 | 793.7 | 629.1 | 638.4 | 611.2 | 638.4 | 638.4 |
| 990.3 | 871.9 | 638.4 | 444.5 | 602.7 | 602.7 | 990.3 | 871.9 | 602.7 | 444.5 | 602.7 | 602.7 |
| 552.7 | 540 | 602.7 | 578.8 | 624.7 | 624.7 | 552.7 | 540 | 624.7 | 578.8 | 624.7 | 624.7 |
| 902.6 | 748.1 | 624.7 | 589.1 | 478.7 | 478.7 | 902.6 | 748.1 | 478.7 | 589.1 | 478.7 | 478.7 |
| 563.6 | 536.4 | 478.7 | 482.7 | 659.1 | 659.1 | 563.6 | 536.4 | 659.1 | 482.7 | 659.1 | 659.1 |
| 650.9 | 571.8 | 659.1 | 608.1 | 976 | 976 | 650.9 | 571.8 | 976 | 608.1 | 976 | 976 |
| 907 | 903.2 | 976 | 718.8 | 876.4 | 876.4 | 907 | 903.2 | 876.4 | 718.8 | 876.4 | 876.4 |
| 698.1 | 754.8 | 876.4 | 547.7 | 521.9 | 521.9 | 698.1 | 754.8 | 521.9 | 547.7 | 521.9 | 521.9 |
| 529.1 | 581 | 521.9 | 484.6 | 537.2 | 537.2 | 529.1 | 581 | 537.2 | 484.6 | 537.2 | 537.2 |
| 708.8 | 611 | 537.2 | 449.4 | 691.4 | 691.4 | 708.8 | 611 | 691.4 | 449.4 | 691.4 | 691.4 |
| 899 | 720 | 691.4 | 453.6 | 621.8 | 621.8 | 899 | 720 | 621.8 | 453.6 | 621.8 | 621.8 |
| 627.7 | 646.4 | 621.8 | 465.1 | 539.6 | 539.6 | 627.7 | 646.4 | 539.6 | 465.1 | 539.6 | 539.6 |
| 689.2 | 662.6 | 539.6 | 370 | 460.9 | 460.9 | 689.2 | 662.6 | 460.9 | 504 | 460.9 | 460.9 |
| 650 | 668.2 | 460.9 | 504 | 886.9 | 886.9 | 650 | 668.2 | 886.9 | | 886.9 | 886.9 |
| 1097.1 | 889.5 | 886.9 | 924.6 | 1098.2 | 1098.2 | 1097.1 | 889.5 | 653 | | 653 | 537.2 |
| 689.1 | 733.6 | 1098.2 | | 653 | 537.2 | 689.1 | 733.6 | 680 | | 680 | 498.1 |
| 650 | 742 | 653 | | 680 | 498.1 | 650 | 742 | 800 | | 800 | 410.9 |
| 660 | 350 | 680 | | 800 | 410.9 | 660 | 350 | 446 | | 446 | 539.9 |
| 590 | 290 | 800 | | 446 | 539.9 | 590 | 290 | 468 | | 468 | 611.2 |
| 700 | 560 | 446 | | 468 | 611.2 | 700 | 560 | | | 537.2 | 444.5 |
| 690 | 770 | 468 | | 267 | 444.5 | 690 | 770 | | | 498.1 | 578.8 |
| 770 | 710 | 267 | | 537.2 | 578.8 | 770 | 710 | | | 410.9 | 589.1 |
| 640 | 730 | | | 498.1 | 589.1 | 640 | 730 | | | 539.9 | 482.7 |
| 520 | 400 | | | 410.9 | 482.7 | 520 | 400 | | | 611.2 | 608.1 |
| 270 | 400 | | | 539.9 | 608.1 | 270 | 400 | | | 444.5 | 718.8 |
| 610 | 350 | | | 611.2 | 718.8 | 610 | 350 | | | 578.8 | 547.7 |
| 816 | 560 | | | 444.5 | 547.7 | 816 | 560 | | | 589.1 | 484.6 |
| 1050 | 871 | | | 578.8 | 484.6 | 1050 | 871 | | | 482.7 | 449.4 |
| 958 | 1061 | | | 589.1 | 449.4 | 958 | 1061 | | | 608.1 | 453.6 |
| 1110 | 912 | | | 482.7 | 453.6 | 1110 | 912 | | | 718.8 | 465.1 |
| 410 | 1000 | | | 608.1 | 465.1 | 410 | 1000 | | | 547.7 | 370 |
| 969 | 630 | | | 718.8 | 370 | 969 | 630 | | | 484.6 | 504 |
| 1361 | 1150 | | | 547.7 | 504 | 1361 | 1150 | | | 449.4 | 924.6 |
| 664 | 1279 | | | 484.6 | 924.6 | 664 | 1279 | | | 453.6 | |
| 1099 | 980 | | | 449.4 | | 1099 | 980 | | | 465.1 | |
| 600 | 1456 | | | 453.6 | | 600 | 1456 | | | 370 | |

Continued on next page

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 480 | 900 | | | 465.1 | | 480 | 900 | | | 504 | |
| 600 | 1580 | | | 370 | | 600 | 1580 | | | 924.6 | |
| 600 | 660 | | | 504 | | 600 | 660 | | | | |
| 250 | 400 | | | 924.6 | | 250 | 400 | | | | |
| 1670 | 330 | | | | | 595 | 330 | | | | |
| 80 | 2480 | | | | | 500 | 950 | | | | |
| 595 | 950 | | | | | 720 | 640 | | | | |
| 500 | 640 | | | | | 600 | 720 | | | | |
| 720 | 720 | | | | | 440 | 690 | | | | |
| 600 | 690 | | | | | 1350 | 520 | | | | |
| 440 | 520 | | | | | 670 | 1000 | | | | |
| 1350 | 1000 | | | | | 500 | 1460 | | | | |
| 670 | 1460 | | | | | | 1520 | | | | |
| 500 | 1520 | | | | | | 1560 | | | | |
| | 1560 | | | | | | 500 | | | | |
| | 500 | | | | | | 630 | | | | |
| | 630 | | | | | | 500 | | | | |
| | 500 | | | | | | 550 | | | | |
| | 550 | | | | | | 1630 | | | | |
| | 275 | | | | | | 870 | | | | |
| | 1630 | | | | | | | | | | |
| | 870 | | | | | | | | | | |
| **719** | **791** | **644** | **538** | **596** | **603** | **713** | **771** | **637** | **525** | **592** | **590** |
| **73** | **98** | **68** | **56** | **49** | **52** | **63** | **83** | **57** | **37** | **43** | **45** |
| 646 | 693 | 576 | 482 | 547 | 551 | 650 | 688 | 580 | 488 | 549 | 545 |
| 792 | 889 | 712 | 594 | 645 | 655 | 776 | 854 | 694 | 562 | 635 | 635 |
| 1,670 | 2,480 | 1,098 | 925 | 1,098 | 1,098 | 1,361 | 1,630 | 976 | 719 | 976 | 976 |
| 80 | 275 | 267 | 370 | 267 | 370 | 250 | 290 | 446 | 411 | 370 | 370 |
| 275 | 394 | 178 | 124 | 165 | 162 | 230 | 327 | 140 | 78 | 141 | 141 |
| 194 | 281 | 126 | 86 | 122 | 117 | 169 | 247 | 101 | 63 | 108 | 105 |
| 54 | 62 | 26 | 19 | 44 | 38 | 52 | 60 | 23 | 17 | 42 | 37 |

| CROP | Barley | Wheat | Beans | Lentils | Combined Pulses | Olive oil |
|---|---|---|---|---|---|---|
| | kg/ha | kg/ha | kg/ha | kg/ha | kg/ha | litres/ha |
| AVERAGE | 713 | 771 | 637 | 525 | 592 | 590 |
| 95% CONFIDENCE LEVEL ± | 63 | 83 | 57 | 37 | 43 | 45 |
| Average - 95% confidence level | 650 | 688 | 580 | 488 | 549 | 545 |
| Average + 95% confidence level | 776 | 854 | 694 | 562 | 635 | 635 |
| MAXIMUM | 1361 | 1630 | 976 | 719 | 976 | 976 |
| MINIMUM | 250 | 290 | 446 | 411 | 370 | 370 |
| **STANDARD DEVIATION** | **230** | **327** | **140** | **78** | **141** | **141** |
| **POPULATION** | 52 | 60 | 23 | 17 | 42 | 37 |

**Reports 2.35b: Chi Square Test**

| | Yields ranked<br>Cypriot yield kg/ha | Observed freq Ob | Expected frequency | (Ob-E)2/E |
|---|---|---|---|---|
| 1 | 290 | 4 | 6.336 | 0.861252525 |
| 2 | 330 | | | |
| 3 | 350 | | | |
| 4 | 350 | | | |
| 5 | 400 | 7 | 7.26 | 0.009311295 |
| 6 | 400 | | | |
| 7 | 400 | | | |
| 8 | 470 | | | |
| 9 | 500 | | | |
| 10 | 500 | | | |
| 11 | 520 | | | |
| 12 | 536.4 | 9 | 5.988 | 1.515054108 |
| 13 | 540 | | | |
| 14 | 550 | | | |
| 15 | 560 | | | |
| 16 | 560 | | | |
| 17 | 571.8 | | | |
| 18 | 581 | | | |
| 19 | 611 | | | |
| 20 | 624.5 | | | |
| 21 | 629.1 | 11 | 5.658 | 5.043648639 |
| 22 | 630 | | | |
| 23 | 630 | | | |
| 24 | 640 | | | |
| 25 | 642.7 | | | |
| 26 | 646.4 | | | |
| 27 | 660 | | | |
| 28 | 662.6 | | | |
| 29 | 666.4 | | | |
| 30 | 668.2 | | | |
| 31 | 690 | | | |
| 32 | 710 | 9 | 9.516 | 0.027979823 |
| 33 | 720 | | | |
| 34 | 720 | | | |
| 35 | 730 | | | |
| 36 | 733.6 | | | |
| 37 | 742 | | | |
| 38 | 748.1 | | | |
| 39 | 754.8 | | | |
| 40 | 770 | | | |
| 41 | 870 | 7 | 5.658 | 0.318303994 |
| 42 | 871 | | | |

| Range from | Range to | Count |
|---|---|---|
| 221 | 270 | 0 |
| 271 | 320 | 1 |
| 321 | 370 | 3 |
| 371 | 420 | 3 |
| 421 | 470 | 1 |
| 471 | 520 | 3 |
| 521 | 570 | 5 |
| 571 | 620 | 3 |
| 621 | 670 | 11 |
| 671 | 720 | 4 |
| 721 | 770 | 6 |
| 771 | 820 | 0 |
| 821 | 870 | 1 |
| 871 | 920 | 6 |
| 921 | 970 | 1 |
| 971 | 1020 | 3 |
| 1021 | 1070 | 1 |
| 1071 | 1120 | 0 |
| 1121 | 1170 | 1 |
| 1171 | 1220 | 0 |

| Range | Count |
|---|---|
| 221-320 | 1 |
| 321-420 | 6 |
| 421-520 | 4 |
| 521-620 | 8 |
| 621-720 | 15 |
| 721-820 | 6 |
| 821-920 | 7 |
| 921-1020 | 4 |
| 1021-1120 | 1 |
| 1121-1220 | 1 |
| 1221-1320 | 1 |
| 1321-1420 | 0 |
| 1421-1520 | 3 |
| 1521-1620 | 2 |
| 1621-1720 | 1 |
| | 60 |

Continued on next page

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 43 | | 871.9 | | | | 1221 | 1270 | |
| 44 | | 889.5 | | | | 1271 | 1320 | 1 |
| 45 | | 900 | | | | 1321 | 1370 | |
| 46 | | 903.2 | | | | 1371 | 1420 | |
| 47 | | 912 | | | | 1421 | 1470 | 2 |
| 48 | | 950 | 4 | 5.988 | 0.660010688 | 1471 | 1520 | 1 |
| 49 | | 980 | | | | 1521 | 1570 | 1 |
| 50 | | 1000 | | | | 1571 | 1620 | 1 |
| 51 | | 1000 | | | | 1621 | 1670 | 1 |
| 52 | | 1061 | 2 | 7.26 | 3.810964187 | | | 60 |
| 53 | | 1150 | | | | | | |
| 54 | | 1279 | 7 | 6.336 | 0.069585859 | | | |
| 55 | | 1456 | | | | | | |
| 56 | | 1460 | | | | | | |
| 57 | | 1520 | | | | | | |
| 58 | | 1560 | | | | | | |
| 59 | | 1580 | | | | | | |
| 60 | | 1630 | | | | | | |
| **AVERAGE** | | **771** | | | | | | |
| **95% CONFIDENCE LEVEL ±** | | **83** | | 1 | | | | |
| **Average - 95% confidence level** | | 688 | | | | | | |
| **Average + 95% confidence level** | | 854 | | | | | | |
| **MAXIMUM** | | 1630 | | | | | | |
| **MINIMUM** | | 290 | | | | | | |
| **STANDARD DEVIATION** | | 327 | | | | | | |
| **POPULATION** | | 60 | | | | | | |

**Report 3.35: Height of Nile in the flood taken from the Nilometer at Roda Isaland (Cairo)**

Ref Willcox 1904: 51. All heights normalised to a reference point 12.25 metres above mean sea level

| | Years AD | No. of Years measured within time span | Max Ht on Roda Island m | Variation around the mean | Lowest Ht on Roda Island Cairo m | Variation around the mean | Rise m | | Variance Rise around the average | Ordered variance Rise around the average |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 639-650 | 11 | 5.91 | -0.52 | 4.49 | -0.19 | 1.42 | 0.55 | -1.2 | -1.2 |
| 1 | 651-675 | 25 | 6.17 | -0.26 | 4.82 | 0.14 | 1.35 | 0.64 | -1.11 | -1.11 |
| 1 | 676-700 | 25 | 5.83 | -0.6 | 3.62 | -1.06 | 2.21 | 0.69 | -1.06 | -1.06 |
| 1 | 701-725 | 25 | 5.89 | -0.54 | 3.88 | -0.8 | 2.01 | 0.73 | -1.02 | -1.02 |
| 1 | 726-750 | 25 | 5.79 | -0.64 | 4.03 | -0.65 | 1.76 | 0.73 | -1.02 | -1.02 |
| 1 | 751-775 | 25 | 5.79 | -0.64 | 4.45 | -0.23 | 1.34 | 0.83 | -0.92 | -0.92 |
| 1 | 776-800 | 25 | 5.68 | -0.75 | 4.04 | -0.64 | 1.64 | 0.94 | -0.81 | -0.81 |
| 1 | 801-825 | 25 | 5.57 | -0.86 | 4.06 | -0.62 | 1.51 | 0.96 | -0.79 | -0.79 |
| 1 | 826.85 | 25 | 5.51 | -0.92 | 3.6 | -1.08 | 1.91 | 1.02 | -0.73 | -0.73 |
| 1 | 851-875 | 25 | 5.73 | -0.7 | 4.9 | 0.22 | 0.83 | 1.02 | -0.73 | -0.73 |
| 1 | 876-900 | 25 | 5.61 | -0.82 | 4.51 | -0.17 | 1.1 | 1.06 | -0.69 | -0.69 |
| 1 | 901-925 | 25 | 5.65 | -0.78 | 3.58 | -1.1 | 2.07 | 1.1 | -0.65 | -0.65 |
| 1 | 926-950 | 25 | 5.91 | -0.52 | 4.4 | -0.28 | 1.51 | 1.24 | -0.51 | -0.51 |
| 1 | 951-975 | 24 | 5.69 | -0.74 | 4.45 | -0.23 | 1.24 | 1.26 | -0.49 | -0.49 |
| 1 | 976-1000 | 25 | 9.4 | 2.97 | 4.6 | -0.08 | 4.8 | 1.26 | -0.49 | -0.49 |
| 1 | 1001-1025 | 25 | 6 | -0.43 | 4.22 | -0.46 | 1.78 | 1.34 | -0.41 | -0.41 |
| 1 | 1026-1050 | 25 | 5.7 | -0.73 | 4.76 | 0.08 | 0.94 | 1.35 | -0.4 | -0.4 |
| 1 | 1051-1075 | 25 | 5.46 | -0.97 | 3.05 | -1.63 | 2.41 | 1.42 | -0.33 | -0.33 |
| 1 | 1076-1100 | 24 | 5.82 | -0.61 | 3.86 | -0.82 | 1.96 | 1.51 | -0.24 | -0.24 |
| 1 | 1101-1125 | 25 | 5.92 | -0.51 | 5.23 | 0.55 | 0.69 | 1.51 | -0.24 | -0.24 |
| 1 | 1126-1150 | 24 | 5.84 | -0.59 | 5.2 | 0.52 | 0.64 | 1.64 | -0.11 | -0.11 |
| 1 | 1151-1175 | 25 | 5.84 | -0.59 | 4.58 | -0.1 | 1.26 | 1.71 | -0.04 | -0.04 |
| 1 | 1176-1200 | 25 | 5.8 | -0.63 | 3.43 | -1.25 | 2.37 | 1.74 | -0.01 | -0.01 |
| 1 | 1201-1225 | 25 | 5.73 | -0.7 | 4.71 | 0.03 | 1.02 | 1.76 | 0.01 | 0.01 |
| 1 | 1226-1250 | 25 | 5.73 | -0.7 | 4.02 | -0.66 | 1.71 | 1.78 | 0.03 | 0.03 |
| 1 | 1251-1275 | 23 | 5.83 | -0.6 | 5.28 | 0.6 | 0.55 | 1.91 | 0.16 | 0.16 |
| 1 | 1276-1300 | 25 | 5.99 | -0.44 | 4.97 | 0.29 | 1.02 | 1.96 | 0.21 | 0.21 |
| 1 | 1301-1325 | 25 | 5.85 | -0.58 | 5.12 | 0.44 | 0.73 | 2.01 | 0.26 | 0.26 |
| 1 | 1326-1350 | 25 | 5.88 | -0.55 | 5.15 | 0.47 | 0.73 | 2.07 | 0.32 | 0.32 |
| 1 | 1351-1375 | 24 | 7.8 | 1.37 | 5.3 | 0.62 | 2.5 | 2.11 | 0.36 | 0.36 |
| 1 | 1376-1400 | 25 | 6.21 | -0.22 | 5.25 | 0.57 | 0.96 | 2.21 | 0.46 | 0.46 |
| 1 | 1401-1425 | 24 | 6.31 | -0.12 | 5.25 | 0.57 | 1.06 | 2.24 | 0.49 | 0.49 |
| 1 | 1501-1525 | 19 | 6.36 | -0.07 | 5.1 | 0.42 | 1.26 | 2.25 | 0.5 | 0.5 |
| 1 | 1576-1600 | 11 | 8.88 | 2.45 | 5.73 | 1.05 | 3.15 | 2.28 | 0.53 | 0.53 |
| 1 | 1601-1625 | 19 | 7.91 | 1.48 | 5.63 | 0.95 | 2.28 | 2.37 | 0.62 | 0.62 |
| 1 | 1701-1725 | 18 | 7.35 | 0.92 | 5.1 | 0.42 | 2.25 | 2.41 | 0.66 | 0.66 |
| 1 | 1726-1750 | 24 | 8.07 | 1.64 | 6.33 | 1.65 | 1.74 | 2.5 | 0.75 | 0.75 |
| 1 | 1751-1775 | 25 | 8.07 | 1.64 | 5.83 | 1.15 | 2.24 | 3.1 | 1.35 | 1.35 |
| 1 | 1776-1800 | 25 | 7.8 | 1.37 | 3.24 | -1.44 | 4.56 | 3.15 | 1.4 | 1.4 |
| 1 | 1826-1850 | 25 | 8.01 | 1.58 | 5.9 | 1.22 | 2.11 | 4.56 | 2.81 | 2.81 |
| 1 | 1851-1875 | 25 | 9.15 | 2.72 | 6.05 | 1.37 | 3.1 | 4.8 | 3.05 | 3.05 |
| 41 | | | | | | | | | | |

Report 3.36a: Statistical analysis of Nile inundation in Report 3.35

| | | | |
|---|---|---|---|
| AVERAGE | 6.43 | 4.68 | 1.75 |
| ± 95% Conf level | 0.34 | 0.24 | 0.29 |
| Average - 95% confidence level | 6.09 | 4.44 | 1.46 |
| Average + 95% confidence level | 6.77 | 4.92 | 2.04 |
| MAXIMUM | 9.4 | 6.33 | 4.8 |
| MINIMUM | 5.46 | 3.05 | 0.55 |
| STANDARD DEV | 1.11 | 0.8 | 0.94 |
| Population | 41 | 41 | 41 |
| MEDIAN | 5.88 | 4.71 | 1.64 |

| Histogram ranges around average | | No. within range |
|---|---|---|
| 0 | LE 0.49 | 0 |
| 0.5 | 0.99 | 8 |
| 1 | 1.49 | 10 |
| 1.5 | 1.99 | 9 |
| 2 | 2.49 | 9 |
| 2.5 | 2.99 | 1 |
| GT 3 | | 4 |
| | | 41 |

**Report 3.36b: Statistical analysis of Nile inundation in Report 3.35**

| Century A.D. | Max Ht on Roda Island Cairo m | Lowest Ht on Roda Island Cairo m | Rise m | Variation from average 242.6 inches | Variation from average 6.16 m |
|---|---|---|---|---|---|
| 7 | 17.5 | 11 | 6.5 | -12.1 | -0.31 |
| 8 | 17.4 | 11.1 | 6.3 | 13.9 | 0.35 |
| 9 | 17.5 | 11.2 | 6.3 | -15.1 | -0.38 |
| 10 | 17.5 | 11.3 | 6.2 | -1.2 | -0.03 |
| 11 | 17.5 | 11.4 | 6.1 | -19.6 | -0.5 |
| 12 | 17.7 | 11.5 | 6.2 | -14.7 | -0.37 |
| 13 | 17.7 | 11.6 | 6.1 | 8.7 | 0.22 |
| 14 | 17.9 | 11.7 | 6.2 | 13 | 0.33 |
| 15 | 18.2 | 11.8 | 6.4 | 1.8 | 0.05 |
| 16 | 18.4 | 11.9 | 6.5 | 26.5 | 0.67 |
| 17 | 18.8 | 12 | 6.8 | 2.4 | 0.06 |
| 18 | 19.1 | 12.1 | 7 | 35.7 | 0.91 |
| 19 | 19.5 | 12.2 | 7.3 | 5.7 | 0.14 |
| | **AVERAGE** | | **6.45** | **3.46** | **0.09** |
| | **± 95% Conf level** | | **0.2** | **8.98** | **0.23** |
| | **Average - 95% confidence level** | | 6.25 | -5.52 | -0.14 |
| | **Average + 95% confidence level** | | 6.65 | 12.44 | 0.32 |
| | **MAXIMUM** | | 7.3 | 35.7 | 0.91 |
| | **MINIMUM** | | 6.1 | -19.6 | -0.5 |
| | **STANDARD DEV** | | 0.37 | 16.52 | 0.42 |
| | **Population** | | 0.28 | 12.73 | 0.32 |

**Report 3.37 : FAO statistic for marginal, average and best land in Kenya**

| | | | | |
|---|---|---|---|---|
| **Semi arid** | | | | |
| c1 | c2 | c3 | c4 | |
| 993 | 2,327 | 6,988 | 8,009 | 18,317 |
| 5.4 | 12.7 | 38.2 | 43.7 | 100 |
| **Barley** | | | | |
| 4,771 | 7,081 | 7,030 | 17,689 | 36,571 |
| 13 | 19.4 | 19.2 | 48.4 | 100 |
| **Wheat** | | | | |
| 2,764 | 6,232 | 5,537 | 16,155 | 30,688 |
| 9 | 20.3 | 18 | 52.6 | 99.9 |
| **Beans** | | | | |
| 4,262 | 5,819 | 7,000 | 12,193 | 29,274 |
| 14.6 | 19.9 | 23.9 | 41.7 | 100.1 |

| Crop | % Cultivatable Land | | | Total |
|---|---|---|---|---|
| **Barley** | 13 | 39 | 48 | 100 |
| **Wheat** | 9 | 38 | 53 | 100 |
| **Beans** | 15 | 43 | 42 | 100 |

| Crop | % Cultivatable Land | | | Total |
|---|---|---|---|---|
| **Barley** | 16 | 39 | 45 | 100 |
| **Wheat** | 12 | 38 | 50 | 100 |
| **Beans** | 18 | 43 | 39 | 100 |

**Report 3.38: Transport Assumptions and total man-years required for movement of taxed produce to the central tax collection point by region**

| | | | |
|---|---|---|---|
| Density olive oil = | 860 | kg/m3 | |
| Density sesame oil = | 925 | kg/m3 | |
| Density of wine = | 1000 | kg/m3 | |

| | |
|---|---|
| 1 chous = | 3 |
| 1 chous = | 0.003 |
| wt of 1 chous of olive oil = | 2.58 |
| wt of 1 chous of sesame oil = | 2.775 |
| wt of 1 chous of wine = | 3 |
| Max. load of oil + containors carried by donkey (Pearle 1940: 372-374) = | 24 |

Assume no. of donkeys within a donkey chain controlled by one man = 10

Assume tax level 5 %

| Cypriot and North Eastern Med. | Barley | Wheat | Pulses | Olive oil | Wine | Units | | |
|---|---|---|---|---|---|---|---|---|
| Max.load carried by a donkey | 75 | 75 | 75 | 61.92 | 72 | kg | | |
| Taxable produce kg/ha (Report 15, area allocated for tax multiplied by yield) | 7,045,783 | 8,611,747 | 11,218,905 | 1,797,340 | 1,389,785 | kg | | |
| No. of individual donkey loads | 4697 | 5741 | 7479 | 1451 | 965 | | | |
| Total | 10438 | 7192 | 8444 | 2416 | 965 | | | |
| No. of donley trains | 1044 | 719 | 844 | 242 | 97 | | | |
| Average distance travelled there and back from farm centre to tax collection point | 10 | 10 | 10 | 10 | 10 | km | | |
| Hours in transit from the farm to the tax collection point and back | 3.13 | 3.13 | 3.13 | 3.13 | 3.13 | hrs/return trip | | |
| Loading and unloading time | 10 | 10 | 10 | 10 | 10 | hrs | | |
| Total transport plus loading/unload | 13.13 | 13.13 | 13.13 | 13.13 | 13.13 | hrs | | |
| Hours worked/day | 10.5 | 10.5 | 10.5 | 10.5 | 10.5 | hr | | |
| Workload to transport grain to the tax collection point | 1305 | 899 | 1055 | 303 | 121 | man-days | | |
| Utilisation factor | 0.84 | 0.84 | 0.84 | 0.84 | 0.84 | | | |
| Utilised man-days to transport grain to the tax collection point/ha | 1554 | 1070 | 1256 | 361 | 144 | man-days | | |
| **Utilised man-years to transport grain to the tax collection point for all farms** | **4.3** | **2.9** | **3.4** | **1** | **0.4** | **man-years** | **Total man-years** | **12** |

| Egypt | Barley | Wheat | Pulses | Wine | Units | | |
|---|---|---|---|---|---|---|---|
| Max.load carried by a donkey | 75 | 75 | 75 | 72 | kg | | |
| Taxable produce kg | 14,640,060 | 4,879,819 | 13,702,488 | 346,774 | kg | | |
| No. of individual donkey loads | 9760 | 3253 | 9135 | 241 | | | |
| Total | 13013 | 12388 | 9135 | 241 | | | |
| No. of donley trains | 1301 | 1239 | 914 | 24 | | | |
| Average distance travelled there and back from farm centre to tax collection point | 10 | 10 | 10 | 10 | km | | |
| Hours in transit from the farm to the tax collection point and back | 3.13 | 3.13 | 3.13 | 3.13 | hrs/return trip | | |
| Loading and unloading time | 10 | 10 | 10 | 10 | hrs | | |
| Total transport plus loading/unload | 13.13 | 13.13 | 13.13 | 13.13 | hrs | | |
| Hours worked/day | 10.5 | 10.5 | 10.5 | 10.5 | hr | | |
| Workload to transport grain to the tax collection point | 1626.9 | 1549 | 1143 | 30 | man-days | | |
| Utilisation factor | 0.84 | 0.84 | 0.84 | 0.84 | | | |
| Utilised man-days to transport grain to the tax collection point/ha | 1937 | 1844 | 1361 | 36 | man-days | | |
| **Utilised man-years to transport grain to the tax collection point for all farms** | **5.3** | **5.1** | **3.7** | **0.1** | **man-years** | **Total man-years** | **14.2** |

**Conversion factors**

| | | |
|---|---|---|
| 1 feddan = | 1.038 | acre |
| 1 acre = | 0.4047 | ha |
| 1 feddan = | 0.4201 | ha |
| 1 stremma = | 0.1 | ha |
| 1 stremma = | 1000 | m2 |
| 1 ha = | 10 | stremma |
| 1 ha = | 10000 | m2 |
| Water density = | 1000 | kg/m3 |
| 1 mile/hr = | 1609 | m/hr |

**Report 3.39: Historic yield rates of wheat and barley in Early American Agriculture (New York Stae 1866-1888)**

| Barley | US bu/acre | kg/ha |
|---|---|---|
| 1866 | 25 | 1297.26 |
| 1867 | 21.5 | 1115.64 |
| 1868 | 21.5 | 1115.64 |
| 1869 | 25 | 1297.26 |
| 1870 | 19.5 | 1011.86 |
| 1871 | 23 | 1193.48 |
| 1872 | 22 | 1141.59 |
| 1873 | 20.5 | 1063.75 |
| 1874 | 23 | 1193.48 |
| 1875 | 22.5 | 1167.53 |
| 1876 | 20.5 | 1063.75 |
| 1877 | 23 | 1193.48 |
| 1878 | 20.5 | 1063.75 |
| 1879 | 22 | 1141.59 |
| 1880 | 22.5 | 1167.53 |
| 1881 | 25 | 1297.26 |
| 1882 | 24 | 1245.37 |
| 1883 | 24.5 | 1271.31 |
| 1884 | 22.5 | 1167.53 |
| 1885 | 23 | 1193.48 |
| 1886 | 23 | 1193.48 |
| 1887 | 20 | 1037.81 |
| 1888 | 23 | 1193.48 |
| Average | | 1166.4 |
| Standard deviation | | 83 |
| Median | | 1167.5 |

| Wheat | US bu/acre | kg/ha | Barley | US bu/acre | kg/ha |
|---|---|---|---|---|---|
| 1866 | 17.5 | 1167.53 | 1866 | 25 | 1297.26 |
| 1867 | 17 | 1134.17 | 1867 | 21.5 | 1115.64 |
| 1868 | 17 | 1134.17 | 1868 | 21.5 | 1115.64 |
| 1869 | 18.5 | 1234.25 | 1869 | 25 | 1297.26 |
| 1870 | 16.5 | 1100.82 | 1870 | 19.5 | 1011.86 |
| 1871 | 20 | 1334.32 | 1871 | 23 | 1193.48 |
| 1872 | 14 | 934.03 | 1872 | 22 | 1141.59 |
| 1873 | 15 | 1000.74 | 1873 | 20.5 | 1063.75 |
| 1874 | 17.5 | 1167.53 | 1874 | 23 | 1193.48 |
| 1875 | 8 | 533.73 | 1875 | 22.5 | 1167.53 |
| 1876 | 17.5 | 1167.53 | 1876 | 20.5 | 1063.75 |
| 1877 | 20.5 | 1367.68 | 1877 | 23 | 1193.48 |
| 1878 | 20 | 1334.32 | 1878 | 20.5 | 1063.75 |
| 1879 | 15.7 | 1047.44 | 1879 | 22 | 1141.59 |
| 1880 | 19 | 1267.61 | 1880 | 22.5 | 1167.53 |
| 1881 | 16.5 | 1100.82 | 1881 | 25 | 1297.26 |
| 1882 | 18.5 | 1234.25 | 1882 | 24 | 1245.37 |
| 1883 | 12 | 800.59 | 1883 | 24.5 | 1271.31 |
| 1884 | 18.5 | 1234.25 | 1884 | 22.5 | 1167.53 |
| 1885 | 17 | 1134.17 | 1885 | 23 | 1193.48 |
| 1886 | 17.5 | 1167.53 | 1886 | 23 | 1193.48 |
| 1887 | 17 | 1134.17 | 1887 | 20 | 1037.81 |
| 1888 | 14.1 | 940.7 | 1888 | 23 | 1193.48 |
| Average | | 1116.2 | Average | | 1166.4 |
| Standard deviation | | 185.4 | Standard deviation | | 83 |
| Median | | 1134.2 | Median | | 1167.5 |

| | | | | | |
|---|---|---|---|---|---|
| Density of dry barley = | **609** | kg/m3 | | | |
| Density of dry wheat = | **769** | kg/m3 | | | |
| 1 acre = | 0.4047 | ha | | | |
| 1 litre = | 0.001 | m3 | | | |
| 1 US bu/acre wheat = | 27 | kg/acre | 66.71608599 | kg/ha | |
| 1 US bu/acre barley = | 21 | kg/acre | 51.8902891 | kg/ha | |

| | | | | |
|---|---|---|---|---|
| 1 bushell = | 36.4 | litres | imperial | |
| 1 bushell = | 35.2 | litres | US | |
| 1 bushell = | 0.0364 | m3 | imperial | |
| 1 bushell = | 0.0352 | m3 | US | |
| 1 bushell = | 28 | kg | imperial | Wheat |
| 1 bushell = | 27 | kg | US | Wheat |
| 1 bushell = | 22 | kg | imperial | Barley |
| 1 bushell = | 21 | kg | US | Barley |

**Sources**

http://www.nass.usda.gov/Statistics_by_State/New_York/Historical_Data/Field%20Crops/FieldCrops.xls

http://www.nass.usda.gov/Statistics_by_State/California/Historical_Data/Barley.pdf

**Report 3.40: Tabulated Cypriot region's yield rates for barley, wheat and pulses taken from Reports 10-13, analysis assumes marginal, average and best land is reprresented by the median**

| | All data from Cypriot regions | | | | | |
|---|---|---|---|---|---|---|
| | Grain | | Pulses | | | |
| | Barley kg/ha | Wheat kg/ha | Total Pulses kg/ha | Barley diff n - (n-1) | Wheat diff n - (n-1) | Pulses diff n - (n-1) |
| 1 | 250 | 290 | 370 | | | |
| 2 | 270 | 330 | 410.9 | 20 | 40 | 40.9 |
| 3 | 410 | 350 | 444.5 | 140 | 20 | 33.6 |
| 4 | 440 | 350 | 446 | 30 | 0 | 1.5 |
| 5 | 480 | 400 | 449.4 | 40 | 50 | 3.4 |
| 6 | 500 | 400 | 453.6 | 20 | 0 | 4.2 |
| 7 | 500 | 400 | 460.9 | 0 | 0 | 7.3 |
| 8 | 520 | 470 | 465.1 | 20 | 70 | 4.2 |
| 9 | 529.1 | 500 | 468 | 9.1 | 30 | 2.9 |
| 10 | 552.7 | 500 | 478.7 | 23.6 | 0 | 10.7 |
| 11 | 563.6 | 520 | 482.7 | 10.9 | 20 | 4 |
| 12 | 590 | 536.4 | 484.6 | 26.4 | 16.4 | 1.9 |
| 13 | 595 | 540 | 498.1 | 5 | 3.6 | 13.5 |
| 14 | 598.7 | 550 | 504 | 3.7 | 10 | 5.9 |
| 15 | 600 | 560 | 521.9 | 1.3 | 10 | 17.9 |
| 16 | 600 | 560 | 537.2 | 0 | 0 | 15.3 |
| 17 | 600 | 571.8 | 537.2 | 0 | 11.8 | 0 |
| 18 | 600 | 581 | 539.6 | 0 | 9.2 | 2.4 |
| 19 | 610 | 611 | 539.9 | 10 | 30 | 0.3 |
| 20 | 627.7 | 624.5 | 542.7 | 17.7 | 13.5 | 2.8 |
| 21 | 640 | 629.1 | 547.7 | 12.3 | 4.6 | 5 |
| 22 | 650 | 630 | 578.8 | 10 | 0.9 | 31.1 |
| 23 | 650 | 630 | 589.1 | 0 | 0 | 10.3 |
| 24 | 650.9 | 640 | 602.7 | 0.9 | 10 | 13.6 |
| 25 | 660 | 642.7 | 608.1 | 9.1 | 2.7 | 5.4 |
| 26 | 664 | 646.4 | 611.2 | 4 | 3.7 | 3.1 |
| 27 | 666.9 | 660 | 621.8 | 2.9 | 13.6 | 10.6 |
| 28 | 670 | 662.6 | 624.7 | 3.1 | 2.6 | 2.9 |
| 29 | 689.1 | 666.4 | 630.9 | 19.1 | 3.8 | 6.2 |
| 30 | 689.2 | 668.2 | 638.4 | 0.1 | 1.8 | 7.5 |
| 31 | 690 | 690 | 650.9 | 0.8 | 21.8 | 12.5 |
| 32 | 695.5 | 710 | 653 | 5.5 | 20 | 2.1 |
| 33 | 698.1 | 720 | 657.2 | 2.6 | 10 | 4.2 |
| 34 | 700 | 720 | 659.1 | 1.9 | 0 | 1.9 |
| 35 | 708.8 | 730 | 680 | 8.8 | 10 | 20.9 |
| 36 | 720 | 733.6 | 691.4 | 11.2 | 3.6 | 11.4 |
| 37 | 733.4 | 742 | 718.8 | 13.4 | 8.4 | 27.4 |
| 38 | 770 | 748.1 | 800 | 36.6 | 6.1 | 81.2 |
| 39 | 793.7 | 754.8 | 876.4 | 23.7 | 6.7 | 76.4 |
| 40 | 816 | 770 | 886.9 | 22.3 | 15.2 | 10.5 |

Continued on next page

| Range | Total Pulses kg/ha |
|---|---|
| Below 400 | 1 |
| 401-450 | 4 |
| 451-500 | 8 |
| 501-550 | 8 |
| 551-600 | 2 |
| 601-650 | 8 |
| 651-700 | 5 |
| 701-750 | 1 |
| 751-800 | 1 |
| 801-850 | 0 |
| 851-900 | 2 |
| 901-950 | 1 |
| 950-1000 | 1 |
| above 1001 | |
| SUM | 42 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 41 | 899 | 870 | 924.6 | 83 | 100 | 37.7 |
| | 42 | 902.6 | 871 | 976 | 3.6 | 1 | 51.4 |
| | 43 | 907 | 871.9 | | 4.4 | 0.9 | |
| | 44 | 958 | 889.5 | | 51 | 17.6 | |
| | 45 | 969 | 900 | | 11 | 10.5 | |
| | 46 | 990.3 | 903.2 | | 21.3 | 3.2 | |
| | 47 | 1050 | 912 | | 59.7 | 8.8 | |
| | 48 | 1097.1 | 950 | | 47.1 | 38 | |
| | 49 | 1099 | 980 | | 1.9 | 30 | |
| | 50 | 1110 | 1000 | | 11 | 20 | |
| | 51 | 1350 | 1000 | | 240 | 0 | |
| | 52 | 1361 | 1061 | | 11 | 61 | |
| | 53 | | 1150 | | | 89 | |
| | 54 | | 1279 | | | 129 | |
| | 55 | | 1456 | | | 177 | |
| | 56 | | 1460 | | | 4 | |
| | 57 | | 1520 | | | 60 | |
| | 58 | | 1560 | | | 40 | |
| | 59 | | 1580 | | | 20 | |
| | 60 | | 1630 | | | 50 | |
| | 61 | | | | | | |
| **Average marginal land yields** | | **407.1** | **399** | **454.8** | | | |
| **Average of average land yields** | | **660** | **713.9** | **562.1** | | | |
| **Average of best land yields** | | **1072.2** | **1454.4** | **801.5** | | | |
| **Median marginal land yields** | | **440** | **400** | **460.9** | | | |
| **Median of average land yields** | | **655.5** | **700** | **595.9** | | | |
| **Median of best land yields** | | **1020.2** | **1490** | **800** | | | |
| **AVERAGE** | | **713** | **771** | **592** | | | |
| **95% CONFIDENCE LEVEL** | | **63** | **83** | **43** | | | |
| **Average - 95% confidence level** | | 650 | 688 | 549 | | | |
| **Average + 95% confidence level** | | 776 | 854 | 635 | | | |
| **MAXIMUM** | | 1361 | 1630 | 976 | | | |
| **MINIMUM** | | 250 | 290 | 370 | | | |
| **STANDARD DEVIATION** | | 230 | 327 | 141 | | | |
| **POPULATION** | | 52 | 60 | 42 | | | |

| Histogram Data | | |
|---|---|---|
| Range | Barley kg/ha | Wheat kg/ha |
| Below 401 | 2 | 7 |
| 401-500 | 5 | 3 |
| 501-600 | 11 | 8 |
| 601-700 | 16 | 13 |
| 701-800 | 5 | 9 |
| 801-900 | 2 | 5 |
| 901-1000 | 5 | 6 |
| 1001-1100 | 3 | 1 |
| 1101-1200 | 1 | 1 |
| 1201-1300 | 0 | 1 |
| 1301-1400 | 2 | 0 |
| 1401-1500 | 0 | 2 |
| 1501-1600 | 0 | 3 |
| above 1601 | 0 | 1 |
| SUM | 52 | 60 |

**Report 3.41: Tabulated Egyptian yield rates for barley, wheat and pulses taken from Reports 3.10 and 3.13, analysis assumes marginal, average and best land is reprresented by the median**

| | Barley yield | Wheat yield | Horse Beans |
|---|---|---|---|
| | kg/ha | kg/ha | kg/ha |
| 1 | 534 | 512 | 679 |
| 2 | 577 | 758 | 833 |
| 3 | 631 | 789 | 980 |
| 4 | 656 | 990 | 986 |
| 5 | 750 | 1,058 | 1,107 |
| 6 | 877 | 1,071 | 1,402 |
| 7 | 893 | 1,089 | 1,428 |
| 8 | 951 | 1,089 | 1,458 |
| 9 | 995 | 1,093 | 1,509 |
| 10 | 1,015 | 1,093 | 1,539 |
| 11 | 1,016 | 1,144 | 1,591 |
| 12 | 1,031 | 1,146 | 1,635 |
| 13 | 1,038 | 1,165 | 1,639 |
| 14 | 1,039 | 1,177 | 1,642 |
| 15 | 1,044 | 1,182 | 1,646 |
| 16 | 1,044 | 1,192 | 1,646 |
| 17 | 1,046 | 1,201 | 1,650 |
| 18 | 1,050 | 1,201 | 1,679 |
| 19 | 1,057 | 1,209 | 1,683 |
| 20 | 1,067 | 1,225 | 1,716 |
| 21 | 1,088 | 1,259 | 1,764 |
| 22 | 1,088 | 1,264 | 1,797 |
| 23 | 1,092 | 1,264 | 1,805 |
| 24 | 1,094 | 1,331 | 1,823 |
| 25 | 1,097 | 1,345 | |
| 26 | 1,135 | 1,364 | |
| 27 | 1,143 | 1,407 | |
| 28 | 1,242 | 1,407 | |
| 29 | 1,250 | 1,438 | |
| 30 | 1,282 | 1,471 | |
| 31 | 1,315 | | |
| 32 | 1,320 | | |
| 33 | 1,337 | | |
| 34 | 1,344 | | |
| 35 | 1,344 | | |
| 36 | 1,380 | | |

| Histogram Data | | |
|---|---|---|
| Range | Barley kg/ha | Wheat kg/ha |
| Below 600 | 2 | 1 |
| 601-800 | 3 | 2 |
| 801-1000 | 4 | 1 |
| 1001-1200 | 16 | 12 |
| 1201-1400 | 11 | 10 |
| 1400+ | 0 | 4 |
| SUM | 36 | 30 |

| Range | Total Pulses kg/ha |
|---|---|
| Below 800 | 1 |
| 801-1000 | 3 |
| 1001-1200 | 1 |
| 1201-1400 | 0 |
| 1401-1600 | 6 |
| 1601-1800 | 11 |
| 1800+ | 2 |
| SUM | 24 |

| | Barley yield | Wheat yield | Horse Beans |
|---|---|---|---|
| | kg/ha | kg/ha | kg/ha |
| **Average marginal land yields** | **702.6** | **686.3** | **917** |
| **Average of average land yields** | **1056.5** | **1155.6** | **1581.9** |
| **Average of best land yields** | **1312.7** | **1394.7** | **1781** |
| **MEDIAN Marginal land** | **656** | **758** | **980** |
| **MEDIAN Average land** | **1,048** | **1,171** | **1,646** |
| **MEDIAN Best land** | **1,320** | **1,407** | **1,797** |
| **AVERAGE** | **1,052** | **1,164** | **1,485** |
| **95% CONFIDENCE LEVEL** | **71** | **74** | **130** |
| **Average - 95% confidence level** | 981 | 1,090 | 1,355 |
| **Average + 95% confidence level** | 1,123 | 1,238 | 1,615 |
| **MAXIMUM** | 1,380 | 1,471 | 1,823 |
| **MINIMUM** | 534 | 512 | 679 |
| **STANDARD DEVIATION** | 217 | 206 | 324 |
| **POPULATION** | 36 | 30 | 24 |

**Report 3.42 : Tabulated Cypriot region's yield rates for olive oil from Reports 2.14, analysis assumes marginal, average and best land is reprresented by the median**

| | Olive oil 1 kg/ha | Olive oil 2 litres/ha | Olive oil 1 diff n -(n-1) | Olive oil 1 diff n -(n-1) |
|---|---|---|---|---|
| | 150 | 174 | 0 | 0 |
| | 160 | 186 | 10 | 12 |
| | 180 | 209 | 20 | 23 |
| | 192 | 223 | 12 | 14 |
| | 220 | 256 | 28 | 33 |
| | 250 | 291 | 30 | 35 |
| | 250 | 291 | 0 | 0 |
| | 250 | 291 | 0 | 0 |
| | 250 | 291 | 0 | 0 |
| | 272 | 316 | 22 | 25 |
| | 275 | 320 | 3 | 4 |
| | 300 | 349 | 25 | 29 |
| | 300 | 349 | 0 | 0 |
| | 300 | 349 | 0 | 0 |
| | 340 | 395 | 40 | 46 |
| | 400 | 465 | 60 | 70 |
| | 400 | 465 | 0 | 0 |
| | 408 | 474 | 8 | 9 |
| | 440 | 512 | 32 | 38 |
| **Average marginal land yields** | **180.4** | **209.6** | | |
| **Average of average land yields** | **271.9** | **316.3** | | |
| **Average of best land yields** | **397.6** | **462.2** | | |
| **MEDIAN Marginal land** | **180** | **209** | | |
| **MEDIAN Average land** | **272** | **316** | | |
| **MEDIAN Best land** | **400** | **465** | | |
| **AVERAGE** | **281** | **327** | | |
| **95% CONFIDENCE LEVEL** | **39** | **45** | | |
| **Average - 95% confidence level** | 242 | 282 | | |
| **Average + 95% confidence level** | 320 | 372 | | |
| **MAXIMUM** | 440 | 512 | | |
| **MINIMUM** | 150 | 174 | | |
| **STANDARD DEVIATION** | 86 | 100 | | |
| **POPULATION** | 19 | 19 | | |

**Report 3.43: Deir el-Bahri granaries**

| | heqat | litre | kg wheat | kg barley |
|---|---|---|---|---|
| **Silo 1** | 645,550 | 3,098,640 | 2,382,855 | 1,451,159 |
| **Silo 2** | 326,620 | 1,567,776 | 1,205,620 | 734,223 |
| **Silo 3** | 45,600 | 218,880 | 168,319 | 102,507 |
| **Silo 4** | 233,400 | 1,120,320 | 861,527 | 524,670 |
| **Silo 5** | 667,770 | 3,205,296 | 2,464,873 | 1,501,108 |
| **Total** | **1,918,940** | **9,210,912** | **7,083,194** | **4,313,667** |
| **No. of men fed per year assuming rest of diet maintained** | | | **20,180** | **12290** |

Ref Balanda 2003: 413 XIth dynaty sarcohagus

| | | |
|---|---|---|
| 1 heqat = | **4.8** | litres |
| 1 litre = | **0.001** | m3 |

Total carbohydrates in Egyptian diet kg/man/yr = 351 from Report 3.4A

**Report 3.44: Pottery requirements**

| | | | | |
|---|---|---|---|---|
| No. of large pots produced per yr | 1200 | per year | 1200 | per year |
| Other small cooking pots produced per yr | 1500 | per year | 1500 | per year |
| Assume workload ratio small to large | 0.5 | | 0.35 | |
| Normalised equivalent workload large pots | 2100 | per year | 2025 | per year |
| Large pot for water | 1 | per family | 2 | per family |
| Cooking/storage | 4 | per family | 8 | per family |
| Assume replacement every | 3 | years | 2 | years |
| No. of families /100,000 sample popul'n | 17889 | | 17889 | |
| Demand for cooking/storage pots/yr | 23852 | | 71556 | |
| Demand for large pots | 5963 | | 17889 | |
| Normalised equivalent large pots | 17889 | | 42934 | |
| No of potters | 9 | | 22 | |
| Assistant preparing clay | 9 | | 22 | |
| Wood/dung/clay gathering | 9 | | 22 | |
| | 27 | | 66 | |

**Report 3.45: Key summary outcomes**

| | Egypt | Cyprus |
|---|---|---|
| Manpower required to feed 100,000 population | 37,205 | 47,490 |
| Manpower required to clothe 100,000 population | 14,659 | 10,430 |
| Manpower available for added value production (average harvest) per 100,000 population | 13,320 | 7,264 |
| Total manpower (assuming population of Egypt 2.2 million and Cyprus 150,000) available for added value production (average harvest) per 100,000 population. | 293,040 | 10,896 |
| Ratio | 27 | 1 |
| Man-years to make 1000 kg copper | 827 | 433 |
| Weight of charcoal required kg to smelt copper and tin, refine copper, and alloy to make 1000 kg of bronze | 57,700 | 58,000 |
| Number of trees used to make this quantity of charcoal (Cyprus oak and Egypt acacia trees) | 13,453 | 9,212 |

| For total population of Egypt | | |
|---|---|---|
| Popul'n of Egypt | 2,200,000 | |
| Area barley | 39,710 | ha |
| Area wheat | 11,572 | ha |
| Wt. of barley seed | 41,973,470 | kg |
| Wt. of wheat seed | 13,377,232 | kg |
| Vol. of barley | 68,922 | m3 |
| Vol. of wheat | 17,396 | m3 |

| | | |
|---|---|---|
| Density of dry barley | 609 | kg/m3 |
| Density of dry wheat | 769 | kg/m3 |

# Famine and Glut

# Egypt

**Report 3.44a: Variation in yields due to variation in Nile inundation**

| | | | | | | |
|---|---|---|---|---|---|---|
| Total energy requirements of 100000 people | 86,065 | Million kcals | | | | |
| Yield Cyprus for barley on marginal, average, best | 408 | 660 | 1,021 | kg/ha | | |
| Yield Cyprus for emmer on marginal, average, best | 399 | 714 | 1,490 | kg/ha | | |
| Yield Cyprus for pulses on marginal, average, best | 455 | 563 | 800 | kg/ha | | |
| Yield Egypt for barley on marginal, average, best | 703 | 1,057 | 1,313 | kg/ha | | |
| Yield Egypt for emmer on marginal, average, best | 687 | 1,156 | 1,395 | kg/ha | | |
| Yield Egypt for pulses on marginal, average, best | 917 | 1,582 | 1,781 | kg/ha | | |
| Sowing rate | 1 to 10 | 10 | % | | | |
| Total area Cyprus grain/pulses ploughing/hoeing case | 69,342 | 69,342 | ha | Food+fodder | 79,360 | 70,415 |
| Total area Cyprus fodder ploughing/hoeing case | 10,018 | 1,073 | ha | | | |
| Total area Egypt grain/pulses ploughing/hoeing case | 37,834 | 37,834 | ha | Food+fodder | 59,659 | 39,981 |
| Total area Egypt fodder ploughing/hoeing case | 21,825 | 2,147 | ha | | | |
| Total agrarian man-years Cyprus ploughing/hoeing | 43,938 | 52,817 | man-years | Assume 60-40% split ploughing | | 47,490 |
| Total agrarian man-years Egypt ploughing/hoeing | 36,298 | 37,593 | man-years | Assume 30-70% split ploughing | | 37,205 |
| Non-agrarian population dry-farming | 56,062 | 47,183 | man-years | Assume 60-40% split ploughing | | 52,510 |
| Non-agrarian population Egypt | 63,702 | 62,407 | man-years | Assume 30-70% split ploughing | | 62,796 |
| Non-productive children and aged | 30,860 | 30,860 | man-years | | | |
| Surplus for Cyprus farming ploughing/hoeing case | 25,202 | 16,323 | man-years | Assume 60-40% split ploughing | | 21,650 |
| Surplus for Egypt ploughing/hoeing case | 32,842 | 31,547 | man-years | Assume 70-30% split ploughing | | 31,936 |

| | |
|---|---|
| Seed corn grain | 10 |
| Seed corn pulse | 10 |
| Wastage grain | 15 |
| Wastage pulses | 15 |

| Region | Egypt | Cyprus |
|---|---|---|
| Population sample | 100,000 | 100,000 |
| Domestic shelter to satisfy popl'n growth | 920 | 920 |
| Domestic pottery | 66 | 66 |
| Less agrarian workforce | 37,205 | 47,490 |
| Less non-productive 55+ & under 6 | 30,860 | 30,860 |
| Less cloth workforce | 14,659 | 10,430 |
| Less elite | 2,970 | 2,970 |
| **Total non-agrarian workforce** | **13,320** | **7,264** |
| **Others** | **86,680** | **92,736** |

| | | |
|---|---|---|
| **No. of years where the harvest fails to meet all the population needs** | Buffer stock | 20 |
| | Ration reduction | 10 |
| **No. of consecutive years where the harvest fails to meet all the population needs** | Buffer stock | 20 |
| | Ration reduction | 10 |

**Report 3.44a2: Energy required to feed 100,000 population + 10% seed corn and 15% wastage**

| | | | |
|---|---|---|---|
| **Grain/pulses energy requirement to maintain healthy population 106 kcals/yr** | **78,835** | **Energy provided by protein, dairy, fats etc.** | 7,230 |
| **Total seed + wastage energy** | **23,234** | | |
| **Total food grown + associated seed corn & wastage (excludes protein and dairy)** | **102,069** | | |

Population 2.2 million

| Years of failed harvests | | | |
|---|---|---|---|
| **Egypt** | **32** | **Cyprus** | **40** |
| **Region** | Consecutive yrs run of failed harvests | | |
| | **2** | **3** | **4** |
| **Egypt** | 12 | 3 | 0 |
| **Cyprus** | 16 | 5 | 0 |

**Years with added value production asssuming harvests produced an average yield (See Report 3.44e below)**

| | | | | |
|---|---|---|---|---|
| No. of years where the harvest fails to meet all the population needs for the case of 20% reduction in rations and a strategic granary stock of 10% | Egypt | 29 | Cyprus | 21 |
| | Region | Years run of consecutive zero value add | | |
| | | 2 | 3 | 4 |
| No. of consecutive years where the harvest fails to meet all the population needs for the case of 20% reduction in rations and a strategic granary stock of 10% | Egypt | 5 | 1 | 0 |
| | Cyprus | 3 | 0 | 0 |

**Report 3.44a3: Average yields from ethnographic data**

| Crop | Yield kg/ha marg'l land | Yield kg/ha av. land | Yield kg/ha best land |
|---|---|---|---|
| Barley | 734 | 1,063 | 1,313 |
| Wheat | 687 | 1,156 | 1,395 |
| Pulses | 917 | 1,582 | 1,781 |
| Wine | 1,753 | 2,921 | 4,382 |

**Report 3.44a4: Best yield case for famine and glut analysis**

| Crop | Yield kg/ha marg'l land | Yield kg/ha av. land | Yield kg/ha best land |
|---|---|---|---|
| Barley | 879 | 1,322 | 1,642 |
| Wheat | 859 | 1,445 | 1,744 |
| Pulses | 1,101 | 1,899 | 2,138 |
| Wine | 1,753 | 3,797 | 5,697 |

**Report 3.44a5: Worst yield case for famine and glut analysis**

| Crop | Yield kg/ha marg'l land | Yield kg/ha av. land | Yield kg/ha best land |
|---|---|---|---|
| Barley | 71 | 529 | 1,182 |
| Wheat | 69 | 578 | 1,256 |
| Pulses | 92 | 791 | 1,603 |
| Wine | 0 | 1,461 | 2,191 |

| | | |
|---|---|---|
| Density of barley | 609 | kg/m3 |
| Density of wheat | 769 | kg/m3 |
| Density of pulses | 500 | kg/m3 |

| | |
|---|---|
| Tot energy requirement less seed/wastage to maintain healthy population | **See Report 3.8e** |
| | **86,065** |
| Total energy required (Workers+sedentary) + seed corn +wastage | 109,299 |

| Rs 20.212 Barley sea xsport | |
|---|---|
| Wt kg | 450,000 |
| Vol m3 | 739 |
| Assume 2*2m | 185 |

| | |
|---|---|
| Total no. agrarian workers in Egypt with pop. of 2.2 million | 818,510 |
| Total no. agrarian workers in Cyprus pop. of 150,000 million | 71,235 |

| Energy Million kcals/100,000 sample population | Average for Egypt |
|---|---|
| Energy of the grain, pulses, olive oil, wine grown + seed corn + protein & dairy | 97,682 |
| Energy of the seed corn | 11617 |
| Tot. food grown + associated seed corn & wastage (excludes protein and dairy) | 102,069 |

| Seed corn manpower assuming 50% ploughing and 50% hoeing | | |
|---|---|---|
| Cyprus | 2,546 | 3,272 |
| Egypt | 2,188 | 2,502 |
| | **Average** | |
| Cyprus | 2,909 | |
| Egypt | 2,345 | |

[illegible] CASE [illegible] EGYPT

| | Iterate | % energy decrease in calories for harvest shortfalls<br>Energy stored in granaries | | | | 20<br>10 | 20,414<br>10,207 | million kcals/yr<br>million kcals/yr | | 20<br>10 |
|---|---|---|---|---|---|---|---|---|---|---|
| ITERATION 1 | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 | Year 6 | Year 7 | Year 8 | Year 9 | Year 10 |
| Granaries strategic stock at beginning of the year | 10,207 | 10,207 | 7,354 | 10,207 | 10,207 | 10,207 | 10,207 | 10,207 | 10,207 | 10,207 |
| Random generated numers between -50 to +50 | 55 | 30 | 88 | 41 | 42 | 75 | 89 | 88 | 35 | 42 |
| Total energy available | 115,107 | 86,032 | 153,486 | 98,825 | 99,988 | 138,367 | 154,649 | 153,486 | 91,847 | 99,988 |
| Energy to feed 100,000 & remain healthy 106 kcals/yr | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 |
| Gross shortfall/surplus | 5,808 | -23,267 | 44,187 | -10,474 | -9,311 | 29,068 | 45,350 | 44,187 | -17,452 | -9,311 |
| Strategy 1: Reduce energy intake | 0 | 20,414 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 0 | 0 | 0 | 10,474 | 9,311 | 0 | 0 | 0 | 17,452 | 9,311 |
| Adjusted energy requirement | 5,808 | -2,853 | 44,187 | 0 | 0 | 29,068 | 45,350 | 44,187 | 0 | 0 |
| Strat 2: Redistribute granaries strat stock if required | 0 | 2,853 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Granary stocks after redistribution | 10,207 | 7,354 | 7,354 | 10,207 | 10,207 | 10,207 | 10,207 | 10,207 | 10,207 | 10,207 |
| Net energy balance | 5,808 | 0 | 44,187 | 0 | 0 | 29,068 | 45,350 | 44,187 | 0 | 0 |
| Stock up granary | 0 | 0 | 2,853 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Availability for redistribution or absorb shortfall | 5,808 | 0 | 41,334 | 0 | 0 | 29,068 | 45,350 | 44,187 | 0 | 0 |
| Granary stock end of year | 10,207 | 7,354 | 10,207 | 10,207 | 10,207 | 10,207 | 10,207 | 10,207 | 10,207 | 10,207 |
| Net energy at the end of the year | 115,107 | 109,299 | 150,633 | 109,299 | 109,299 | 138,367 | 154,649 | 153,486 | 109,299 | 109,299 |
| Seed corn energy shortfall | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Manpower adjustment for seed corn shortfall | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Pop'n/100,000 supported in the current yr | 105,314 | 100,000 | 137,817 | 100,000 | 100,000 | 126,595 | 141,492 | 140,428 | 100,000 | 100,000 |
| Shortfall or addit'l workforce that could be supported | 5,314 | 0 | 37,817 | 0 | 0 | 26,595 | 41,492 | 40,428 | 0 | 0 |
| Egyptian surplus available for added value production | 18,634 | 13,320 | 51,137 | 13,320 | 13,320 | 39,915 | 54,812 | 53,748 | 13,320 | 13,320 |

| ITERATION 2 | Year 11 | Year 12 | Year 13 | Year 14 | Year 15 | Year 16 | Year 17 | Year 18 | Year 19 | Year 20 |
|---|---|---|---|---|---|---|---|---|---|---|
| Granaries strategic stock at beginning of the year | 10,207 | 0 | 10,207 | 10,207 | 0 | 0 | 0 | 5,808 | 0 | 0 |
| Random generated numers between -50 to +50 | 9 | 79 | 69 | 23 | 50 | 10 | 55 | 13 | 11 | 27 |
| Total energy available | 61,609 | 143,019 | 131,389 | 77,891 | 109,292 | 62,772 | 115,107 | 66,261 | 63,935 | 82,543 |
| Energy to feed 100,000 & remain healthy 106 kcals/yr | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 |
| Gross shortfall/surplus | -47,690 | 33,720 | 22,090 | -31,408 | -7 | -46,527 | 5,808 | -43,038 | -45,364 | -26,756 |
| Strategy 1: Reduce energy intake | 20,414 | 0 | 0 | 20,414 | 0 | 20,414 | 0 | 20,414 | 20,414 | 20,414 |
| | 0 | 0 | 0 | 0 | 7 | 0 | 0 | 0 | 0 | 0 |
| Adjusted energy requirement | -27,276 | 33,720 | 22,090 | -10,994 | 0 | -26,113 | 5,808 | -22,624 | -24,950 | -6,342 |
| Strat 2: Redistribute granaries strat stock if required | 10,207 | 0 | 0 | 10,207 | 0 | 0 | 0 | 5,808 | 0 | 0 |
| Granary stocks after redistribution | 0 | 0 | 10,207 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Net energy balance | -17,069 | 33,720 | 22,090 | -787 | 0 | -26,113 | 5,808 | -16,816 | -24,950 | -6,342 |
| Stock up granary | 0 | 10,207 | 0 | 0 | 0 | 0 | 5,808 | 0 | 0 | 0 |
| Availability for redistribution or absorb shortfall | -17,069 | 23,513 | 22,090 | -787 | 0 | -26,113 | 0 | -16,816 | -24,950 | -6,342 |
| Granary stock end of year | 0 | 10,207 | 10,207 | 0 | 0 | 0 | 5,808 | 0 | 0 | 0 |
| Net energy at the end of the year | 92,230 | 132,812 | 131,389 | 108,512 | 109,299 | 83,186 | 109,299 | 92,483 | 84,349 | 102,957 |
| Seed corn energy shortfall | -5,452 | 0 | 0 | 0 | 0 | -11,617 | 0 | -5,199 | -11,617 | 0 |
| Manpower adjustment for seed corn shortfall | -1,101 | 0 | 0 | 0 | 0 | -2,345 | 0 | -1,049 | -2,345 | 0 |
| Pop'n/100,000 supported in the current yr | 83,282 | 121,513 | 120,211 | 99,280 | 100,000 | 73,764 | 100,000 | 83,566 | 74,828 | 94,198 |
| Shortfall or addit'l workforce that could be supported | -16,718 | 21,513 | 20,211 | -720 | 0 | -26,236 | 0 | -16,434 | -25,172 | -5,802 |
| Egyptian surplus available for added value production | 0 | 34,833 | 33,531 | 12,600 | 13,320 | 0 | 13,320 | 0 | 0 | 7,518 |

| ITERATION 3 | Year 21 | Year 22 | Year 23 | Year 24 | Year 25 | Year 26 | Year 27 | Year 28 | Year 29 | Year 30 |
|---|---|---|---|---|---|---|---|---|---|---|
| Granaries strategic stock at beginning of the year | 0 | 10,207 | 10,207 | 10,207 | 0 | 10,207 | 10,207 | 10,207 | 10,207 | 10,207 |
| Random generated numers between -50 to +50 | 63 | 67 | 71 | 10 | 77 | 45 | 91 | 87 | 65 | 25 |
| Total energy available | 124,411 | 129,063 | 133,715 | 62,772 | 140,693 | 103,477 | 156,975 | 152,323 | 126,737 | 80,217 |
| Energy to feed 100,000 & remain healthy 106 kcals/yr | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 |
| Gross shortfall/surplus | 15,112 | 19,764 | 24,416 | -46,527 | 31,394 | -5,822 | 47,676 | 43,024 | 17,438 | -29,082 |
| Strategy 1: Reduce energy intake | 0 | 0 | 0 | 20,414 | 0 | 0 | 0 | 0 | 0 | 20,414 |
| | 0 | 0 | 0 | 0 | 0 | 5,822 | 0 | 0 | 0 | 0 |
| Adjusted energy requirement | 15,112 | 19,764 | 24,416 | -26,113 | 31,394 | 0 | 47,676 | 43,024 | 17,438 | -8,668 |
| Strat 2: Redistribute granaries strat stock if required | 0 | 0 | 0 | 10,207 | 0 | 0 | 0 | 0 | 0 | 8,668 |
| Granary stocks after redistribution | 0 | 10,207 | 10,207 | 0 | 0 | 10,207 | 10,207 | 10,207 | 10,207 | 1,539 |
| Net energy balance | 15,112 | 19,764 | 24,416 | -15,906 | 31,394 | 0 | 47,676 | 43,024 | 17,438 | 0 |
| Stock up granary | 10,207 | 0 | 0 | 0 | 10,207 | 0 | 0 | 0 | 0 | 0 |
| Availability for redistribution or absorb shortfall | 4,905 | 19,764 | 24,416 | -15,906 | 21,187 | 0 | 47,676 | 43,024 | 17,438 | 0 |
| Granary stock end of year | 10,207 | 10,207 | 10,207 | 0 | 10,207 | 10,207 | 10,207 | 10,207 | 10,207 | 1,539 |
| Net energy at the end of the year | 114,204 | 129,063 | 133,715 | 93,393 | 130,486 | 109,299 | 156,975 | 152,323 | 126,737 | 109,299 |
| Seed corn energy shortfall | 0 | 0 | 0 | -4,289 | 0 | 0 | 0 | 0 | 0 | 0 |
| Manpower adjustment for seed corn shortfall | 0 | 0 | 0 | -866 | 0 | 0 | 0 | 0 | 0 | 0 |
| Pop'n/100,000 supported in the current yr | 104,488 | 118,083 | 122,339 | 84,581 | 119,384 | 100,000 | 143,620 | 139,364 | 115,954 | 100,000 |
| Shortfall or addit'l workforce that could be supported | 4,488 | 18,083 | 22,339 | -15,419 | 19,384 | 0 | 43,620 | 39,364 | 15,954 | 0 |
| Egyptian surplus available for added value production | 17,808 | 31,403 | 35,659 | 0 | 32,704 | 13,320 | 56,940 | 52,684 | 29,274 | 13,320 |

| ITERATION 4 | Year 31 | Year 32 | Year 33 | Year 34 | Year 35 | Year 36 | Year 37 | Year 38 | Year 39 | Year 40 |
|---|---|---|---|---|---|---|---|---|---|---|
| Granaries strategic stock at beginning of the year | 1,539 | 10,207 | 10,207 | 2,702 | 0 | 10,207 | 3,865 | 0 | 0 | 10,207 |
| Random generated numers between -50 to +50 | 87 | 74 | 26 | 14 | 84 | 27 | 15 | 38 | 100 | 38 |
| Total energy available | 152,323 | 137,204 | 81,380 | 67,424 | 148,834 | 82,543 | 68,587 | 95,336 | 167,442 | 95,336 |
| Energy to feed 100,000 & remain healthy 106 kcals/yr | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 |
| Gross shortfall/surplus | 43,024 | 27,905 | -27,919 | -41,875 | 39,535 | -26,756 | -40,712 | -13,963 | 58,143 | -13,963 |
| Strategy 1: Reduce energy intake | 0 | 0 | 20,414 | 20,414 | 0 | 20,414 | 20,414 | 0 | 0 | 0 |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 13,963 | 0 | 13,963 |
| Adjusted energy requirement | 43,024 | 27,905 | -7,505 | -21,461 | 39,535 | -6,342 | -20,298 | 0 | 58,143 | 0 |
| Strat 2: Redistribute granaries strat stock if required | 0 | 0 | 7,505 | 2,702 | 0 | 6,342 | 3,865 | 0 | 0 | 0 |
| Granary stocks after redistribution | 1,539 | 10,207 | 2,702 | 0 | 0 | 3,865 | 0 | 0 | 0 | 10,207 |
| Net energy balance | 43,024 | 27,905 | 0 | -18,759 | 39,535 | 0 | -16,433 | 0 | 58,143 | 0 |
| Stock up granary | 8,668 | 0 | 0 | 0 | 10,207 | 0 | 0 | 0 | 10,207 | 0 |
| Availability for redistribution or absorb shortfall | 34,356 | 27,905 | 0 | -18,759 | 29,328 | 0 | -16,433 | 0 | 47,936 | 0 |
| Granary stock end of year | 10,207 | 10,207 | 2,702 | 0 | 10,207 | 3,865 | 0 | 0 | 10,207 | 10,207 |
| Net energy at the end of the year | 143,655 | 137,204 | 109,299 | 90,540 | 138,627 | 109,299 | 92,866 | 109,299 | 157,235 | 109,299 |
| Seed corn energy shortfall | 0 | 0 | 0 | -7,142 | 0 | 0 | -4,816 | 0 | 0 | 0 |
| Manpower adjustment for seed corn shortfall | 0 | 0 | 0 | -1,442 | 0 | 0 | -972 | 0 | 0 | 0 |
| Pop'n/100,000 supported in the current yr | 131,433 | 125,531 | 100,000 | 81,395 | 126,833 | 100,000 | 83,993 | 100,000 | 143,858 | 100,000 |
| Shortfall or addit'l workforce that could be supported | 31,433 | 25,531 | 0 | -18,605 | 26,833 | 0 | -16,007 | 0 | 43,858 | 0 |
| Egyptian surplus available for added value production | 44,753 | 38,851 | 13,320 | 0 | 40,153 | 13,320 | 0 | 13,320 | 57,178 | 13,320 |

| ITERATION 5 | Year 41 | Year 42 | Year 43 | Year 44 | Year 45 | Year 46 | Year 47 | Year 48 | Year 49 | Year 50 |
|---|---|---|---|---|---|---|---|---|---|---|
| Granaries strategic stock at beginning of the year | 10,207 | 0 | 0 | 0 | 0 | 0 | 0 | 10,207 | 10,207 | 0 |
| Random generated numers between -50 to +50 | 20 | 45 | 8 | 50 | 2 | 6 | 80 | 97 | 22 | 29 |
| Total energy available | 74,402 | 103,477 | 60,446 | 109,292 | 53,468 | 58,120 | 144,182 | 163,953 | 76,728 | 84,869 |
| Energy to feed 100,000 & remain healthy 106 kcals/yr | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 |
| Gross shortfall/surplus | -34,897 | -5,822 | -48,853 | -7 | -55,831 | -51,179 | 34,883 | 54,654 | -32,571 | -24,430 |
| Strategy 1: Reduce energy intake | 20,414 | 0 | 20,414 | 0 | 20,414 | 20,414 | 0 | 0 | 20,414 | 20,414 |
| | 0 | 5,822 | 0 | 7 | 0 | 0 | 0 | 0 | 0 | 0 |
| Adjusted energy requirement | -14,483 | 0 | -28,439 | 0 | -35,417 | -30,765 | 34,883 | 54,654 | -12,157 | -4,016 |
| Strat 2: Redistribute granaries strat stock if required | 10,207 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10,207 | 0 |
| Granary stocks after redistribution | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10,207 | 0 | 0 |
| Net energy balance | -4,276 | 0 | -28,439 | 0 | -35,417 | -30,765 | 34,883 | 54,654 | -1,950 | -4,016 |
| Stock up granary | 0 | 0 | 0 | 0 | 0 | 0 | 10,207 | 0 | 0 | 0 |
| Availability for redistribution or absorb shortfall | -4,276 | 0 | -28,439 | 0 | -35,417 | -30,765 | 24,676 | 54,654 | -1,950 | -4,016 |
| Granary stock end of year | 0 | 0 | 0 | 0 | 0 | 0 | 10,207 | 10,207 | 0 | 0 |
| Net energy at the end of the year | 105,023 | 109,299 | 80,860 | 109,299 | 73,882 | 78,534 | 133,975 | 163,953 | 107,349 | 105,283 |
| Seed corn energy shortfall | 0 | 0 | -11,617 | 0 | -11,617 | -11,617 | 0 | 0 | 0 | 0 |
| Manpower adjustment for seed corn shortfall | 0 | 0 | -2,345 | 0 | -2,345 | -2,345 | 0 | 0 | 0 | 0 |
| Pop'n/100,000 supported in the current yr | 96,088 | 100,000 | 71,636 | 100,000 | 65,251 | 69,507 | 122,577 | 150,004 | 98,216 | 96,326 |
| Shortfall or addit'l workforce that could be supported | -3,912 | 0 | -28,364 | 0 | -34,749 | -30,493 | 22,577 | 50,004 | -1,784 | -3,674 |
| Egyptian surplus available for added value production | 9,408 | 13,320 | 0 | 13,320 | 0 | 0 | 35,897 | 63,324 | 11,536 | 9,646 |

| ITERATION 6 | Year 51 | Year 52 | Year 53 | Year 54 | Year 55 | Year 56 | Year 57 | Year 58 | Year 59 | Year 60 |
|---|---|---|---|---|---|---|---|---|---|---|
| Granaries strategic stock at beginning of the year | 0 | 0 | 10,207 | 10,207 | 0 | 0 | 0 | 10,207 | 0 | 0 |
| Random generated numers between -50 to +50 | 44 | 65 | 60 | 9 | 14 | 48 | 68 | 6 | 30 | 72 |
| Total energy available | 102,314 | 126,737 | 120,922 | 61,609 | 67,424 | 106,966 | 130,226 | 58,120 | 86,032 | 134,878 |
| Energy to feed 100,000 & remain healthy 106 kcals/yr | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 |
| Gross shortfall/surplus | -6,985 | 17,438 | 11,623 | -47,690 | -41,875 | -2,333 | 20,927 | -51,179 | -23,267 | 25,579 |
| Strategy 1: Reduce energy intake | 0 | 0 | 0 | 20,414 | 20,414 | 0 | 0 | 20,414 | 20,414 | 0 |
| | 6,985 | 0 | 0 | 0 | 0 | 2,333 | 0 | 0 | 0 | 0 |
| Adjusted energy requirement | 0 | 17,438 | 11,623 | -27,276 | -21,461 | 0 | 20,927 | -30,765 | -2,853 | 25,579 |
| Strat 2: Redistribute granaries strat stock if required | 0 | 0 | 0 | 10,207 | 0 | 0 | 0 | 10,207 | 0 | 0 |
| Granary stocks after redistribution | 0 | 0 | 10,207 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Net energy balance | 0 | 17,438 | 11,623 | -17,069 | -21,461 | 0 | 20,927 | -20,558 | -2,853 | 25,579 |
| Stock up granary | 0 | 10,207 | 0 | 0 | 0 | 0 | 10,207 | 0 | 0 | 10,207 |
| Availability for redistribution or absorb shortfall | 0 | 7,231 | 11,623 | -17,069 | -21,461 | 0 | 10,720 | -20,558 | -2,853 | 15,372 |
| Granary stock end of year | 0 | 10,207 | 10,207 | 0 | 0 | 0 | 10,207 | 0 | 0 | 10,207 |
| Net energy at the end of the year | 109,299 | 116,530 | 120,922 | 92,230 | 87,838 | 109,299 | 120,019 | 88,741 | 106,446 | 124,671 |
| Seed corn energy shortfall | 0 | 0 | 0 | -5,452 | -9,844 | 0 | 0 | -8,941 | 0 | 0 |
| Manpower adjustment for seed corn shortfall | 0 | 0 | 0 | -1,101 | -1,987 | 0 | 0 | -1,805 | 0 | 0 |
| Pop'n/100,000 supported in the current yr | 100,000 | 106,616 | 110,634 | 83,282 | 78,378 | 100,000 | 109,808 | 79,386 | 97,390 | 114,064 |
| Shortfall or addit'l workforce that could be supported | 0 | 6,616 | 10,634 | -16,718 | -21,622 | 0 | 9,808 | -20,614 | -2,610 | 14,064 |
| Egyptian surplus available for added value production | 13,320 | 19,936 | 23,954 | 0 | 0 | 13,320 | 23,128 | 0 | 10,710 | 27,384 |

| ITERATION 7 | Year 61 | Year 62 | Year 63 | Year 64 | Year 65 | Year 66 | Year 67 | Year 68 | Year 69 | Year 70 |
|---|---|---|---|---|---|---|---|---|---|---|
| Granaries strategic stock at beginning of the year | 10,207 | 10,207 | 10,207 | 0 | 10,207 | 10,207 | 10,207 | 1,539 | 5,808 | 0 |
| Random generated numers between -50 to +50 | 77 | 78 | 15 | 71 | 49 | 44 | 25 | 55 | 13 | 23 |
| Total energy available | 140,693 | 141,856 | 68,587 | 133,715 | 108,129 | 102,314 | 80,217 | 115,107 | 66,261 | 77,891 |
| Energy to feed 100,000 & remain healthy 106 kcals/yr | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 |
| Gross shortfall/surplus | 31,394 | 32,557 | -40,712 | 24,416 | -1,170 | -6,985 | -29,082 | 5,808 | -43,038 | -31,408 |
| Strategy 1: Reduce energy intake | 0 | 0 | 20,414 | 0 | 0 | 0 | 20,414 | 0 | 20,414 | 20,414 |
| | 0 | 0 | 0 | 0 | 1,170 | 6,985 | 0 | 0 | 0 | 0 |
| Adjusted energy requirement | 31,394 | 32,557 | -20,298 | 24,416 | 0 | 0 | -8,668 | 5,808 | -22,624 | -10,994 |
| Strat 2: Redistribute granaries strat stock if required | 0 | 0 | 10,207 | 0 | 0 | 0 | 8,668 | 0 | 5,808 | 0 |
| Granary stocks after redistribution | 10,207 | 10,207 | 0 | 0 | 10,207 | 10,207 | 1,539 | 1,539 | 0 | 0 |
| Net energy balance | 31,394 | 32,557 | -10,091 | 24,416 | 0 | 0 | 0 | 5,808 | -16,816 | -10,994 |
| Stock up granary | 0 | 0 | 0 | 10,207 | 0 | 0 | 0 | 4,269 | 0 | 0 |
| Availability for redistribution or absorb shortfall | 31,394 | 32,557 | -10,091 | 14,209 | 0 | 0 | 0 | 1,539 | -16,816 | -10,994 |
| Granary stock end of year | 10,207 | 10,207 | 0 | 10,207 | 10,207 | 10,207 | 1,539 | 5,808 | 0 | 0 |
| Net energy at the end of the year | 140,693 | 141,856 | 99,208 | 123,508 | 109,299 | 109,299 | 109,299 | 110,838 | 92,483 | 98,305 |
| Seed corn energy shortfall | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -5,199 | 0 |
| Manpower adjustment for seed corn shortfall | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1,049 | 0 |
| Pop'n/100,000 supported in the current yr | 128,723 | 129,787 | 90,768 | 113,000 | 100,000 | 100,000 | 100,000 | 101,408 | 83,566 | 89,941 |
| Shortfall or addit'l workforce that could be supported | 28,723 | 29,787 | -9,232 | 13,000 | 0 | 0 | 0 | 1,408 | -16,434 | -10,059 |
| Egyptian surplus available for added value production | 42,043 | 43,107 | 0 | 26,320 | 13,320 | 13,320 | 13,320 | 14,728 | 0 | 0 |

| ITERATION 8 | Year 71 | Year 72 | Year 73 | Year 74 | Year 75 | Year 76 | Year 77 | Year 78 | Year 79 | Year 80 |
|---|---|---|---|---|---|---|---|---|---|---|
| Granaries strategic stock at beginning of the year | 0 | 8,134 | 10,207 | 10,207 | 10,207 | 10,207 | 10,207 | 10,207 | 10,207 | 10,207 |
| Random generated numers between -50 to +50 | 57 | 66 | 63 | 43 | 56 | 87 | 88 | 46 | 56 | 14 |
| Total energy available | 117,433 | 127,900 | 124,411 | 101,151 | 116,270 | 152,323 | 153,486 | 104,640 | 116,270 | 67,424 |
| Energy to feed 100,000 & remain healthy 106 kcals/yr | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 |
| Gross shortfall/surplus | 8,134 | 18,601 | 15,112 | -8,148 | 6,971 | 43,024 | 44,187 | -4,659 | 6,971 | -41,875 |
| Strategy 1: Reduce energy intake | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 20,414 |
| | 0 | 0 | 0 | 8,148 | 0 | 0 | 0 | 4,659 | 0 | 0 |
| Adjusted energy requirement | 8,134 | 18,601 | 15,112 | 0 | 6,971 | 43,024 | 44,187 | 0 | 6,971 | -21,461 |
| Strat 2: Redistribute granaries strat stock if required | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10,207 |
| Granary stocks after redistribution | 0 | 8,134 | 10,207 | 10,207 | 10,207 | 10,207 | 10,207 | 10,207 | 10,207 | 0 |
| Net energy balance | 8,134 | 18,601 | 15,112 | 0 | 6,971 | 43,024 | 44,187 | 0 | 6,971 | -11,254 |
| Stock up granary | 8,134 | 2,073 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Availability for redistribution or absorb shortfall | 0 | 16,528 | 15,112 | 0 | 6,971 | 43,024 | 44,187 | 0 | 6,971 | -11,254 |
| Granary stock end of year | 8,134 | 10,207 | 10,207 | 10,207 | 10,207 | 10,207 | 10,207 | 10,207 | 10,207 | 0 |
| Net energy at the end of the year | 109,299 | 125,827 | 124,411 | 109,299 | 116,270 | 152,323 | 153,486 | 109,299 | 116,270 | 98,045 |
| Seed corn energy shortfall | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Manpower adjustment for seed corn shortfall | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Pop'n/100,000 supported in the current yr | 100,000 | 115,122 | 113,826 | 100,000 | 106,378 | 139,364 | 140,428 | 100,000 | 106,378 | 89,703 |
| Shortfall or addit'l workforce that could be supported | 0 | 15,122 | 13,826 | 0 | 6,378 | 39,364 | 40,428 | 0 | 6,378 | -10,297 |
| Egyptian surplus available for added value production | 13,320 | 28,442 | 27,146 | 13,320 | 19,698 | 52,684 | 53,748 | 13,320 | 19,698 | 0 |

| ITERATION 9 | Year 81 | Year 82 | Year 83 | Year 84 | Year 85 | Year 86 | Year 87 | Year 88 | Year 89 | Year 90 |
|---|---|---|---|---|---|---|---|---|---|---|
| Granaries strategic stock at beginning of the year | 0 | 10,207 | 3,865 | 10,207 | 0 | 10,207 | 10,207 | 10,207 | 0 | 0 |
| Random generated numers between -50 to +50 | 67 | 27 | 97 | 23 | 66 | 33 | 35 | 14 | 9 | 39 |
| Total energy available | 129,063 | 82,543 | 163,953 | 77,891 | 127,900 | 89,521 | 91,847 | 67,424 | 61,609 | 96,499 |
| Energy to feed 100,000 & remain healthy 106 kcals/yr | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 |
| Gross shortfall/surplus | 19,764 | -26,756 | 54,654 | -31,408 | 18,601 | -19,778 | -17,452 | -41,875 | -47,690 | -12,800 |
| Strategy 1: Reduce energy intake | 0 | 20,414 | 0 | 20,414 | 0 | 0 | 0 | 20,414 | 20,414 | 0 |
| | 0 | 0 | 0 | 0 | 0 | 19,778 | 17,452 | 0 | 0 | 12,800 |
| Adjusted energy requirement | 19,764 | -6,342 | 54,654 | -10,994 | 18,601 | 0 | 0 | -21,461 | -27,276 | 0 |
| Strat 2: Redistribute granaries strat stock if required | 0 | 6,342 | 0 | 10,207 | 0 | 0 | 0 | 10,207 | 0 | 0 |
| Granary stocks after redistribution | 0 | 3,865 | 3,865 | 0 | 0 | 10,207 | 10,207 | 0 | 0 | 0 |
| Net energy balance | 19,764 | 0 | 54,654 | -787 | 18,601 | 0 | 0 | -11,254 | -27,276 | 0 |
| Stock up granary | 10,207 | 0 | 6,342 | 0 | 10,207 | 0 | 0 | 0 | 0 | 0 |
| Availability for redistribution or absorb shortfall | 9,557 | 0 | 48,312 | -787 | 8,394 | 0 | 0 | -11,254 | -27,276 | 0 |
| Granary stock end of year | 10,207 | 3,865 | 10,207 | 0 | 10,207 | 10,207 | 10,207 | 0 | 0 | 0 |
| Net energy at the end of the year | 118,856 | 109,299 | 157,611 | 108,512 | 117,693 | 109,299 | 109,299 | 98,045 | 82,023 | 109,299 |
| Seed corn energy shortfall | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -11,617 | 0 |
| Manpower adjustment for seed corn shortfall | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -2,345 | 0 |
| Pop'n/100,000 supported in the current yr | 108,744 | 100,000 | 144,202 | 99,280 | 107,680 | 100,000 | 100,000 | 89,703 | 72,700 | 100,000 |
| Shortfall or addit'l workforce that could be supported | 8,744 | 0 | 44,202 | -720 | 7,680 | 0 | 0 | -10,297 | -27,300 | 0 |
| Egyptian surplus available for added value production | 22,064 | 13,320 | 57,522 | 0 | 21,000 | 13,320 | 13,320 | 0 | 0 | 13,320 |

| ITERATION 10 | Year 91 | Year 92 | Year 93 | Year 94 | Year 95 | Year 96 | Year 97 | Year 98 | Year 99 | Year 100 |
|---|---|---|---|---|---|---|---|---|---|---|
| Granaries strategic stock at beginning of the year | 0 | 10,207 | 0 | 0 | 0 | 0 | 0 | 10,207 | 10,207 | 0 |
| Random generated numers between -50 to +50 | 95 | 18 | 26 | 20 | 8 | 48 | 96 | 38 | 22 | 2 |
| Total energy available | 161,627 | 72,076 | 81,380 | 74,402 | 60,446 | 106,966 | 162,790 | 95,336 | 76,728 | 53,468 |
| Energy to feed 100,000 & remain healthy 106 kcals/yr | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 | 109,299 |
| Gross shortfall/surplus | 52,328 | -37,223 | -27,919 | -34,897 | -48,853 | -2,333 | 53,491 | -13,963 | -32,571 | -55,831 |
| Strategy 1: Reduce energy intake | 0 | 20,414 | 20,414 | 20,414 | 20,414 | 0 | 0 | 0 | 20,414 | 20,414 |
| | 0 | 0 | 0 | 0 | 0 | 2,333 | 0 | 13,963 | 0 | 0 |
| Adjusted energy requirement | 52,328 | -16,809 | -7,505 | -14,483 | -28,439 | 0 | 53,491 | 0 | -12,157 | -35,417 |
| Strat 2: Redistribute granaries strat stock if required | 0 | 10,207 | 0 | 0 | 0 | 0 | 0 | 0 | 10,207 | 0 |
| Granary stocks after redistribution | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10,207 | 0 | 0 |
| Net energy balance | 52,328 | -6,602 | -7,505 | -14,483 | -28,439 | 0 | 53,491 | 0 | -1,950 | -35,417 |
| Stock up granary | 10,207 | 0 | 0 | 0 | 0 | 0 | 10,207 | 0 | 0 | 0 |
| Availability for redistribution or absorb shortfall | 42,121 | -6,602 | -7,505 | -14,483 | -28,439 | 0 | 43,284 | 0 | -1,950 | -35,417 |
| Granary stock end of year | 10,207 | 0 | 0 | 0 | 0 | 0 | 10,207 | 10,207 | 0 | 0 |
| Net energy at the end of the year | 151,420 | 102,697 | 101,794 | 94,816 | 80,860 | 109,299 | 152,583 | 109,299 | 107,349 | 73,882 |
| Seed corn energy shortfall | 0 | 0 | 0 | -2,866 | -11,617 | 0 | 0 | 0 | 0 | -11,617 |
| Manpower adjustment for seed corn shortfall | 0 | 0 | 0 | -579 | -2,345 | 0 | 0 | 0 | 0 | -2,345 |
| Pop'n/100,000 supported in the current yr | 138,537 | 93,960 | 93,134 | 86,170 | 71,636 | 100,000 | 139,601 | 100,000 | 98,216 | 65,251 |
| Shortfall or addit'l workforce that could be supported | 38,537 | -6,040 | -6,866 | -13,830 | -28,364 | 0 | 39,601 | 0 | -1,784 | -34,749 |
| Egyptian surplus available for added value production | 51,857 | 0 | 0 | 0 | 0 | 13,320 | 52,921 | 13,320 | 0 | 0 |

| Iteration | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Min/Max |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Minimum Net energy balance | 86,032 | 61,609 | 62,772 | 67,424 | 53,468 | 58,120 | 66,261 | 67,424 | 61,609 | 53,468 | **53,468** |
| Maximum Net energy balance | 154,649 | 143,019 | 156,975 | 167,442 | 163,953 | 134,878 | 141,856 | 153,486 | 163,953 | 162,790 | **167,442** |

Report 3.44c1: Famine analysis

| Yield variation | Net energy yr end including gains and losses million kcals/yr | Workers per 100,000 that could be supported in current yr | Surplus or unfed manpower | Years of failed harvests | Run of two years | Run of three years | Run of four years | 0 -4,999 | -5,000 -9,999 | -10,000 -14,999 | -15,000 -19,999 | -20,000 -24,999 | -25,000 -29,999 | -30,000 -34,999 | -35,000 -39,999 | -40,000 -100,000 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 55 | 115,107 | 105,314 | 5,314 | 0 | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 30 | 109,299 | 100,000 | 0 | 0 | 0 | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 88 | 150,633 | 137,817 | 37,817 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 41 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 42 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 75 | 138,367 | 126,595 | 26,595 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 89 | 154,649 | 141,492 | 41,492 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 88 | 153,486 | 140,428 | 40,428 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 35 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 42 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 92,230 | 83,282 | -16,718 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 79 | 132,812 | 121,513 | 21,513 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 69 | 131,389 | 120,211 | 20,211 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 23 | 108,512 | 99,280 | -720 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 50 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 83,186 | 73,764 | -26,236 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 55 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 13 | 92,483 | 83,566 | -16,434 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 11 | 84,349 | 74,828 | -25,172 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 27 | 102,957 | 94,198 | -5,802 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 63 | 114,204 | 104,488 | 4,488 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 67 | 129,063 | 118,083 | 18,083 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 71 | 133,715 | 122,339 | 22,339 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 93,393 | 84,581 | -15,419 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 77 | 130,486 | 119,384 | 19,384 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 45 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 91 | 156,975 | 143,620 | 43,620 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 87 | 152,323 | 139,364 | 39,364 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 65 | 126,737 | 115,954 | 15,954 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 25 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 87 | 143,655 | 131,433 | 31,433 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 74 | 137,204 | 125,531 | 25,531 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 26 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 14 | 90,540 | 81,395 | -18,605 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 84 | 138,627 | 126,833 | 26,833 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 27 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 15 | 92,866 | 83,993 | -16,007 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 38 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 100 | 157,235 | 143,858 | 43,858 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 38 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | 105,023 | 96,088 | -3,912 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 45 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

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| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8 | 80,860 | 71,636 | -28,364 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 50 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 73,882 | 65,251 | -34,749 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 6 | 78,534 | 69,507 | -30,493 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 80 | 133,975 | 122,577 | 22,577 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 97 | 163,953 | 150,004 | 50,004 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 22 | 107,349 | 98,216 | -1,784 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 29 | 105,283 | 96,326 | -3,674 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 44 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 65 | 116,530 | 106,616 | 6,616 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 60 | 120,922 | 110,634 | 10,634 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 92,230 | 83,282 | -16,718 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 14 | 87,838 | 78,378 | -21,622 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| 48 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 68 | 120,019 | 109,808 | 9,808 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 88,741 | 79,386 | -20,614 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| 30 | 106,446 | 97,390 | -2,610 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 72 | 124,671 | 114,064 | 14,064 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 77 | 140,693 | 128,723 | 28,723 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 78 | 141,856 | 129,787 | 29,787 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 15 | 99,208 | 90,768 | -9,232 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 71 | 123,508 | 113,000 | 13,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 49 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 44 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 25 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 55 | 110,838 | 101,408 | 1,408 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 13 | 92,483 | 83,566 | -16,434 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 23 | 98,305 | 89,941 | -10,059 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 57 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 66 | 125,827 | 115,122 | 15,122 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 63 | 124,411 | 113,826 | 13,826 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 43 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 56 | 116,270 | 106,378 | 6,378 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 87 | 152,323 | 139,364 | 39,364 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 88 | 153,486 | 140,428 | 40,428 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 46 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 56 | 116,270 | 106,378 | 6,378 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 14 | 98,045 | 89,703 | -10,297 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 67 | 118,856 | 108,744 | 8,744 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 27 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 97 | 157,611 | 144,202 | 44,202 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 23 | 108,512 | 99,280 | -720 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 66 | 117,693 | 107,680 | 7,680 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 33 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 35 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 14 | 98,045 | 89,703 | -10,297 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 82,023 | 72,700 | -27,300 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 39 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 95 | 151,420 | 138,537 | 38,537 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

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| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 18 | 102,697 | 93,960 | -6,040 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 26 | 101,794 | 93,134 | -6,866 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | 94,816 | 86,170 | -13,830 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 80,860 | 71,636 | -28,364 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 48 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 96 | 152,583 | 139,601 | 39,601 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 38 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 22 | 107,349 | 98,216 | -1,784 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 73,882 | 65,251 | -34,749 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 4,619 | 11,454,774 | 10,449,514 | | 32 | 12 | 3 | 0 | 7 | 4 | 4 | 7 | 2 | 5 | 3 | 0 | 0 |
| | | | | | | | | | | | | | | | | 32 |
| Maximum | 163,953 | 150,004 | 50,004 | | | | | | | | | | | | | |
| Minimum | 73,882 | 65,251 | -34,749 | | | | | | | | | | | | | |

| CHECKSUM | | |
|---|---|---|
| 4,619 | 0 | 4,619 |
| 11,454,774 | 0 | 11,454,774 |
| 10,449,514 | 0 | 10,449,514 |
| 386,280 | 1,898,316 | -1,512,036 |
| 32 | 32 | 0 |

**Report 3.44d: Summary of increase buffer levels**

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 32 | 12 | 3 | 0 | 7 | 4 | 4 | 7 | 2 | 5 | 3 | 0 | 0 |
| 20 | 0 | 38 | 14 | 3 | 0 | 3 | 7 | 7 | 1 | 8 | 8 | 4 | 0 | 0 |
| Rations % reduction | Granary buffer % | No. of years of failed harvests | Run of 2 failed harvests | Run of 3 failed harvests | Run of 4 failed harvests | 0 -4,999 | -5,000 -9,999 | -10,000 -14,999 | -15,000 -19,999 | -20,000 -24,999 | -25,000 -29,999 | -30,000 -34,999 | -35,000 -39,999 | -40,000 -100,000 |
| 20 | 5 | 37 | 14 | 3 | 0 | 7 | 7 | 4 | 4 | 6 | 6 | 3 | 0 | 0 |
| 20 | 10 | 32 | 12 | 3 | 0 | 7 | 4 | 4 | 7 | 2 | 5 | 3 | 0 | 0 |
| 20 | 15 | 27 | 10 | 3 | 0 | 4 | 6 | 7 | 1 | 2 | 4 | 3 | 0 | 0 |
| 20 | 20 | 24 | 9 | 2 | 0 | 5 | 7 | 2 | 2 | 2 | 4 | 2 | 0 | 0 |
| 20 | 25 | 20 | 6 | 1 | 0 | 6 | 3 | 2 | 2 | 3 | 2 | 2 | 0 | 0 |

**Report 3.44e1: Value add analysis**

| | Buffer stock set at 10%: Total no. of years where harvest failed to reach average yield | Buffer stock set at 10%: Run of 2 years where harvest failed to reach average yield | Buffer stock set at 10%: Run of 3 years where harvest failed to reach average yield | Buffer stock set at 15%: Total no. of years where harvest failed to reach average yield | Buffer stock set at 15%: Run of 2 years where harvest failed to reach average yield | Buffer stock set at 15%: Run of 3 years where harvest failed to reach average yield |
|---|---|---|---|---|---|---|
| Egypt | 32 | 12 | 3 | 27 | 10 | 3 |
| Cyprus | 40 | 16 | 5 | 38 | 15 | 4 |
| | | | | | 2 | |

Below average but above fame set 1, average set 2, above average set 3

| Yield variation | Workers per 100,000 that could be supported in current yr | Value add | Years with value add | Run of two years with value add | Run of three years with value add | Run of four years with value add | Years of value add within cohort ranges: Cohort 0 4,999 | Cohort 5,000 9,999 | Cohort 10,000 14,999 | Cohort 15,000 19,999 | Cohort 20,000 24,999 | Cohort 25,000 29,999 | Cohort 30,000 34,999 | Cohort 35,000 39,999 | Cohort 40,000 100,000 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 55 | 105,314 | 0 | 0 | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 30 | 100,000 | 13,320 | 1 | 0 | | | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 88 | 137,817 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 41 | 100,000 | 13,320 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 42 | 100,000 | 13,320 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 75 | 126,595 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 89 | 141,492 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 88 | 140,428 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 35 | 100,000 | 13,320 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 42 | 100,000 | 13,320 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 83,282 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 79 | 121,513 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 69 | 120,211 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 23 | 99,280 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 50 | 100,000 | 13,320 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 73,764 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 55 | 100,000 | 13,320 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 13 | 83,566 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | 74,828 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 27 | 94,198 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 63 | 104,488 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 67 | 118,083 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 71 | 122,339 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 84,581 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 77 | 119,384 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 45 | 100,000 | 13,320 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 91 | 143,620 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 87 | 139,364 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 65 | 115,954 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 25 | 100,000 | 13,320 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 87 | 131,433 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 74 | 125,531 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 26 | 100,000 | 13,320 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 14 | 81,395 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

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| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 84 | 126,833 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 27 | 100,000 | 13,320 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 15 | 83,993 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 38 | 100,000 | 13,320 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 100 | 143,858 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 38 | 100,000 | 13,320 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | 96,088 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 45 | 100,000 | 13,320 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 71,636 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 50 | 100,000 | 13,320 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 65,251 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 69,507 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 80 | 122,577 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 97 | 150,004 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 22 | 98,216 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 29 | 96,326 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 44 | 100,000 | 13,320 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 65 | 106,616 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 60 | 110,634 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 83,282 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 14 | 78,378 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 48 | 100,000 | 13,320 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 68 | 109,808 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 79,386 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 30 | 97,390 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 72 | 114,064 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 77 | 128,723 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 78 | 129,787 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 15 | 90,768 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 71 | 113,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 49 | 100,000 | 13,320 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 44 | 100,000 | 13,320 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 25 | 100,000 | 13,320 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 55 | 101,408 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 13 | 83,566 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 23 | 89,941 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 57 | 100,000 | 13,320 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 66 | 115,122 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 63 | 113,826 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 43 | 100,000 | 13,320 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 56 | 106,378 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 87 | 139,364 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 88 | 140,428 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 46 | 100,000 | 13,320 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 56 | 106,378 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 14 | 89,703 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 67 | 108,744 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 27 | 100,000 | 13,320 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 97 | 144,202 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

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| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 23 | 99,280 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 66 | 107,680 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 33 | 100,000 | 13,320 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 35 | 100,000 | 13,320 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 14 | 89,703 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 9 | 72,700 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 39 | 100,000 | 13,320 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 95 | 138,537 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 18 | 93,960 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 26 | 93,134 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 20 | 86,170 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 8 | 71,636 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 48 | 100,000 | 13,320 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 96 | 139,601 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 38 | 100,000 | 13,320 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 22 | 98,216 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 2 | 65,251 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 4,619 | 10,449,514 | 386,280 | 29 | 5 | 1 | 0 | 0 | 0 | 29 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Yrs with value add production for the case 15% strategic granary stock + 20% reduction in rations | | | | | 100 | | | | | | | | | | 29 | |

| | Rations % reduction | Granary buffer % | Years with value add | Run of two years with value add | Run of three years with value add | Run of four years with value add | Years of value add within cohort ranges: Cohort 0 4,999 | Cohort 5,000 9,999 | Cohort 10,000 14,999 | Cohort 15,000 19,999 | Cohort 20,000 24,999 | Cohort 25,000 29,999 | Cohort 30,000 34,999 | Cohort 35,000 39,999 | Cohort 40,000 100,000 | Total years of value add |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 20 | 10 | | | | | | | | | | | | | | 0 |
| | | | | | | | | | | | | | | | | |
| LT av harvests but some added value | | | 15 | 3 | 1 | 0 | 5 | 3 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 15 |
| Average harvests | 20 | 10 | 29 | 5 | 1 | 0 | 0 | 0 | 29 | 0 | 0 | 0 | 0 | 0 | 0 | 29 |
| Harvests GT than average | | | 39 | 15 | 5 | 0 | 2 | 7 | 4 | 4 | 4 | 5 | 1 | 5 | 7 | 39 |
| | | | 83 | 23 | 7 | 0 | 7 | 10 | 40 | 4 | 4 | 5 | 1 | 5 | 7 | 83 |
| | 20 | 10 | | | | | | | | | | | | | | |
| | 20 | 20 | | | | | | | | | | | | | | |
| | 20 | 25 | | | | | | | | | | | | | | |

Report 3.44c2 : Below, average, and above average analysis on the manpower available for non-basic activities

| | | | Below average harvests | | Average harvests | | Above average harvests | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Yield variation | Workers per 100,000 that could be supported in current yr | Workers per 100,000 that could be supported in current yr | Value add | Workers per 100,000 that could be supported in current yr | Value add | Workers per 100,000 that could be supported in current yr | Value add | | No. of years where no value add can be supported | No. of years where harvest can support 100,000 or more |
| 1 | 55 | 105,314 | 0 | 0 | 0 | 0 | 5,314 | 1 | 1 | 0 | 1 |
| 2 | 30 | 100,000 | 0 | 0 | 14,158 | 1 | 0 | 0 | 1 | 0 | 1 |
| 3 | 88 | 137,817 | 0 | 0 | 0 | 0 | 37,817 | 1 | 1 | 0 | 1 |
| 4 | 41 | 100,000 | 0 | 0 | 14,158 | 1 | 0 | 0 | 1 | 0 | 1 |
| 5 | 42 | 100,000 | 0 | 0 | 14,158 | 1 | 0 | 0 | 1 | 0 | 1 |
| 6 | 75 | 126,595 | 0 | 0 | 0 | 0 | 26,595 | 1 | 1 | 0 | 1 |
| 7 | 89 | 141,492 | 0 | 0 | 0 | 0 | 41,492 | 1 | 1 | 0 | 1 |
| 8 | 88 | 140,428 | 0 | 0 | 0 | 0 | 40,428 | 1 | 1 | 0 | 1 |
| 9 | 35 | 100,000 | 0 | 0 | 14,158 | 1 | 0 | 0 | 1 | 0 | 1 |
| 10 | 42 | 100,000 | 0 | 0 | 14,158 | 1 | 0 | 0 | 1 | 0 | 1 |
| 11 | 9 | 83,282 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 12 | 79 | 121,513 | 0 | 0 | 0 | 0 | 21,513 | 1 | 1 | 0 | 1 |
| 13 | 69 | 120,211 | 0 | 0 | 0 | 0 | 20,211 | 1 | 1 | 0 | 1 |
| 14 | 23 | 99,280 | 13,438 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 15 | 50 | 100,000 | 0 | 0 | 14,158 | 1 | 0 | 0 | 1 | 0 | 1 |
| 16 | 10 | 73,764 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 17 | 55 | 100,000 | 0 | 0 | 14,158 | 1 | 0 | 0 | 1 | 0 | 1 |
| 18 | 13 | 83,566 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 19 | 11 | 74,828 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 20 | 27 | 94,198 | 8,356 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 21 | 63 | 104,488 | 0 | 0 | 0 | 0 | 4,488 | 1 | 1 | 0 | 1 |
| 22 | 67 | 118,083 | 0 | 0 | 0 | 0 | 18,083 | 1 | 1 | 0 | 1 |
| 23 | 71 | 122,339 | 0 | 0 | 0 | 0 | 22,339 | 1 | 1 | 0 | 1 |
| 24 | 10 | 84,581 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 25 | 77 | 119,384 | 0 | 0 | 0 | 0 | 19,384 | 1 | 1 | 0 | 1 |
| 26 | 45 | 100,000 | 0 | 0 | 14,158 | 1 | 0 | 0 | 1 | 0 | 1 |
| 27 | 91 | 143,620 | 0 | 0 | 0 | 0 | 43,620 | 1 | 1 | 0 | 1 |
| 28 | 87 | 139,364 | 0 | 0 | 0 | 0 | 39,364 | 1 | 1 | 0 | 1 |
| 29 | 65 | 115,954 | 0 | 0 | 0 | 0 | 15,954 | 1 | 1 | 0 | 1 |
| 30 | 25 | 100,000 | 0 | 0 | 14,158 | 1 | 0 | 0 | 1 | 0 | 1 |
| 31 | 87 | 131,433 | 0 | 0 | 0 | 0 | 31,433 | 1 | 1 | 0 | 1 |
| 32 | 74 | 125,531 | 0 | 0 | 0 | 0 | 25,531 | 1 | 1 | 0 | 1 |
| 33 | 26 | 100,000 | 0 | 0 | 14,158 | 1 | 0 | 0 | 1 | 0 | 1 |
| 34 | 14 | 81,395 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 35 | 84 | 126,833 | 0 | 0 | 0 | 0 | 26,833 | 1 | 1 | 0 | 1 |
| 36 | 27 | 100,000 | 0 | 0 | 14,158 | 1 | 0 | 0 | 1 | 0 | 1 |
| 37 | 15 | 83,993 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 38 | 38 | 100,000 | 0 | 0 | 14,158 | 1 | 0 | 0 | 1 | 0 | 1 |
| 39 | 100 | 143,858 | 0 | 0 | 0 | 0 | 43,858 | 1 | 1 | 0 | 1 |
| 40 | 38 | 100,000 | 0 | 0 | 14,158 | 1 | 0 | 0 | 1 | 0 | 1 |

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| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 41 | 20 | 96,088 | 10,246 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 42 | 45 | 100,000 | 0 | 0 | 14,158 | 1 | 0 | 0 | 1 | 0 | 1 |
| 43 | 8 | 71,636 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 44 | 50 | 100,000 | 0 | 0 | 14,158 | 1 | 0 | 0 | 1 | 0 | 1 |
| 45 | 2 | 65,251 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 46 | 6 | 69,507 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 47 | 80 | 122,577 | 0 | 0 | 0 | 0 | 22,577 | 1 | 1 | 0 | 1 |
| 48 | 97 | 150,004 | 0 | 0 | 0 | 0 | 50,004 | 1 | 1 | 0 | 1 |
| 49 | 22 | 98,216 | 12,374 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 50 | 29 | 96,326 | 10,484 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 51 | 44 | 100,000 | 0 | 0 | 14,158 | 1 | 0 | 0 | 1 | 0 | 1 |
| 52 | 65 | 106,616 | 0 | 0 | 0 | 0 | 6,616 | 1 | 1 | 0 | 1 |
| 53 | 60 | 110,634 | 0 | 0 | 0 | 0 | 10,634 | 1 | 1 | 0 | 1 |
| 54 | 9 | 83,282 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 55 | 14 | 78,378 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 56 | 48 | 100,000 | 0 | 0 | 14,158 | 1 | 0 | 0 | 1 | 0 | 1 |
| 57 | 68 | 109,808 | 0 | 0 | 0 | 0 | 9,808 | 1 | 1 | 0 | 1 |
| 58 | 6 | 79,386 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 59 | 30 | 97,390 | 11,548 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 60 | 72 | 114,064 | 0 | 0 | 0 | 0 | 14,064 | 1 | 1 | 0 | 1 |
| 61 | 77 | 128,723 | 0 | 0 | 0 | 0 | 28,723 | 1 | 1 | 0 | 1 |
| 62 | 78 | 129,787 | 0 | 0 | 0 | 0 | 29,787 | 1 | 1 | 0 | 1 |
| 63 | 15 | 90,768 | 4,926 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 64 | 71 | 113,000 | 0 | 0 | 0 | 0 | 13,000 | 1 | 1 | 0 | 1 |
| 65 | 49 | 100,000 | 0 | 0 | 14,158 | 1 | 0 | 0 | 1 | 0 | 1 |
| 66 | 44 | 100,000 | 0 | 0 | 14,158 | 1 | 0 | 0 | 1 | 0 | 1 |
| 67 | 25 | 100,000 | 0 | 0 | 14,158 | 1 | 0 | 0 | 1 | 0 | 1 |
| 68 | 55 | 101,408 | 0 | 0 | 0 | 0 | 1,408 | 1 | 1 | 0 | 1 |
| 69 | 13 | 83,566 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 70 | 23 | 89,941 | 4,099 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 71 | 57 | 100,000 | 0 | 0 | 14,158 | 1 | 0 | 0 | 1 | 0 | 1 |
| 72 | 66 | 115,122 | 0 | 0 | 0 | 0 | 15,122 | 1 | 1 | 0 | 1 |
| 73 | 63 | 113,826 | 0 | 0 | 0 | 0 | 13,826 | 1 | 1 | 0 | 1 |
| 74 | 43 | 100,000 | 0 | 0 | 14,158 | 1 | 0 | 0 | 1 | 0 | 1 |
| 75 | 56 | 106,378 | 0 | 0 | 0 | 0 | 6,378 | 1 | 1 | 0 | 1 |
| 76 | 87 | 139,364 | 0 | 0 | 0 | 0 | 39,364 | 1 | 1 | 0 | 1 |
| 77 | 88 | 140,428 | 0 | 0 | 0 | 0 | 40,428 | 1 | 1 | 0 | 1 |
| 78 | 46 | 100,000 | 0 | 0 | 14,158 | 1 | 0 | 0 | 1 | 0 | 1 |
| 79 | 56 | 106,378 | 0 | 0 | 0 | 0 | 6,378 | 1 | 1 | 0 | 1 |
| 80 | 14 | 89,703 | 3,861 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 81 | 67 | 108,744 | 0 | 0 | 0 | 0 | 8,744 | 1 | 1 | 0 | 1 |
| 82 | 27 | 100,000 | 0 | 0 | 14,158 | 1 | 0 | 0 | 1 | 0 | 1 |
| 83 | 97 | 144,202 | 0 | 0 | 0 | 0 | 44,202 | 1 | 1 | 0 | 1 |
| 84 | 23 | 99,280 | 13,438 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 85 | 66 | 107,680 | 0 | 0 | 0 | 0 | 7,680 | 1 | 1 | 0 | 1 |
| 86 | 33 | 100,000 | 0 | 0 | 14,158 | 1 | 0 | 0 | 1 | 0 | 1 |
| 87 | 35 | 100,000 | 0 | 0 | 14,158 | 1 | 0 | 0 | 1 | 0 | 1 |
| 88 | 14 | 89,703 | 3,861 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 89 | 9 | 72,700 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |

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| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 90 | 39 | 100,000 | 0 | 0 | 14,158 | 1 | 0 | 0 | 1 | 0 | 1 |
| 91 | 95 | 138,537 | 0 | 0 | 0 | 0 | 38,537 | 1 | 1 | 0 | 1 |
| 92 | 18 | 93,960 | 8,118 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 93 | 26 | 93,134 | 7,292 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 94 | 20 | 86,170 | 328 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 95 | 8 | 71,636 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 96 | 48 | 100,000 | 0 | 0 | 14,158 | 1 | 0 | 0 | 1 | 0 | 1 |
| 97 | 96 | 139,601 | 0 | 0 | 0 | 0 | 39,601 | 1 | 1 | 0 | 1 |
| 98 | 38 | 100,000 | 0 | 0 | 14,158 | 1 | 0 | 0 | 1 | 0 | 1 |
| 99 | 22 | 98,216 | 12,374 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 100 | 2 | 65,251 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| For a population cohortb of 100,000 | | | 124,743 | 15 | 410,582 | 29 | 931,138 | 39 | | 17 | 68 |
| For total population of | 2.2 | million | 2,744,346 | | 9,032,804 | | 20,485,036 | | | 100 | |

| Number of harvests in any 100 that enabled non-basic activities to take place without taking other measures such as importing grain | Egypt | Cyprus | Non-basic activities: Egypt | Non-basic activities: Cyprus |
|---|---|---|---|---|
| | Number of years/100 | Number of years/100 | Number of years/100 | Number of years/100 |
| Category 1: No. of years where no non-agrarian activity could be supported | 17 | 34 | | |
| Category 2: Less than average but with some non-basic activity | 15 | 6 | 15 | 6 |
| Category 3: Average harvests | 29 | 21 | 29 | 21 |
| Category 4: Above average harvests | 39 | 39 | 39 | 39 |
| **Totals** | **100** | **100** | **83** | **66** |

| Sum of all non-basic manpower for a 100 year period | | |
|---|---|---|
| **Harvest category** | **Egyptian man-years** | **Cypriot man-years** |
| Category 1: No. of years where no non-agrarian activity could be supported | 0 | 0 |
| Category 2: Less than average but with some non-basic activity | 2,744,346 | 40,308 |
| Category 3: Average harvests | 9,032,804 | 276,255 |
| Category 4: Above average harvests | 20,485,036 | 1,723,869 |
| **Totals** | **32,262,186** | **2,040,432** |
| **Ratio Egytian to Cypriot value add manpower ove a 100 year period** | **16** | |

Report 3.44f: Glut analysis

| Yield variation | Net energy at end of year after taking into account gains and | Population per 100,000 that could be supported in the current | Surplus or unfed manpower | Years where harvest + 20% reduction in rations + strategy to maintain 15% buffer in granaries failed to feed all the population | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Yrs m/p gt 100,000 | Run of two years | Run of three years | Run of four years | 0 4,999 | 5,000 9,999 | 10,000 14,999 | 15,000 19,999 | 20,000 24,999 | 25,000 29,999 | 30,000 34,999 | 35,000 39,999 | 40,000 100,000 |
| 55 | 115,107 | 105,314 | 5,314 | 1 | | | | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 30 | 109,299 | 100,000 | 0 | 0 | 0 | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 88 | 150,633 | 137,817 | 37,817 | 1 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 41 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 42 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 75 | 138,367 | 126,595 | 26,595 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 89 | 154,649 | 141,492 | 41,492 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 88 | 153,486 | 140,428 | 40,428 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 35 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 42 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 92,230 | 83,282 | -16,718 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 79 | 132,812 | 121,513 | 21,513 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| 69 | 131,389 | 120,211 | 20,211 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| 23 | 108,512 | 99,280 | -720 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 50 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 83,186 | 73,764 | -26,236 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 55 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 13 | 92,483 | 83,566 | -16,434 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | 84,349 | 74,828 | -25,172 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 27 | 102,957 | 94,198 | -5,802 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 63 | 114,204 | 104,488 | 4,488 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 67 | 129,063 | 118,083 | 18,083 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 71 | 133,715 | 122,339 | 22,339 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| 10 | 93,393 | 84,581 | -15,419 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 77 | 130,486 | 119,384 | 19,384 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 45 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 91 | 156,975 | 143,620 | 43,620 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 87 | 152,323 | 139,364 | 39,364 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 65 | 126,737 | 115,954 | 15,954 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 25 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 87 | 143,655 | 131,433 | 31,433 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 74 | 137,204 | 125,531 | 25,531 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 26 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 14 | 90,540 | 81,395 | -18,605 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 84 | 138,627 | 126,833 | 26,833 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 27 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 15 | 92,866 | 83,993 | -16,007 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 38 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 100 | 157,235 | 143,858 | 43,858 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 38 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | 105,023 | 96,088 | -3,912 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 45 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

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| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8 | 80,860 | 71,636 | -28,364 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 50 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 73,882 | 65,251 | -34,749 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 78,534 | 69,507 | -30,493 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 80 | 133,975 | 122,577 | 22,577 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| 97 | 163,953 | 150,004 | 50,004 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 22 | 107,349 | 98,216 | -1,784 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 29 | 105,283 | 96,326 | -3,674 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 44 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 65 | 116,530 | 106,616 | 6,616 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 60 | 120,922 | 110,634 | 10,634 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 92,230 | 83,282 | -16,718 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 14 | 87,838 | 78,378 | -21,622 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 48 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 68 | 120,019 | 109,808 | 9,808 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 88,741 | 79,386 | -20,614 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 30 | 106,446 | 97,390 | -2,610 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 72 | 124,671 | 114,064 | 14,064 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 77 | 140,693 | 128,723 | 28,723 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 78 | 141,856 | 129,787 | 29,787 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 15 | 99,208 | 90,768 | -9,232 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 71 | 123,508 | 113,000 | 13,000 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 49 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 44 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 25 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 55 | 110,838 | 101,408 | 1,408 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 13 | 92,483 | 83,566 | -16,434 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 23 | 98,305 | 89,941 | -10,059 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 57 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 66 | 125,827 | 115,122 | 15,122 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 63 | 124,411 | 113,826 | 13,826 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 43 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 56 | 116,270 | 106,378 | 6,378 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 87 | 152,323 | 139,364 | 39,364 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 88 | 153,486 | 140,428 | 40,428 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 46 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 56 | 116,270 | 106,378 | 6,378 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 14 | 98,045 | 89,703 | -10,297 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 67 | 118,856 | 108,744 | 8,744 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 27 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 97 | 157,611 | 144,202 | 44,202 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 23 | 108,512 | 99,280 | -720 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 66 | 117,693 | 107,680 | 7,680 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 33 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 35 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 14 | 98,045 | 89,703 | -10,297 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 82,023 | 72,700 | -27,300 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 39 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 95 | 151,420 | 138,537 | 38,537 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |

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| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 18 | 102,697 | 93,960 | -6,040 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 26 | 101,794 | 93,134 | -6,866 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | 94,816 | 86,170 | -13,830 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 80,860 | 71,636 | -28,364 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 48 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 96 | 152,583 | 139,601 | 39,601 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 38 | 109,299 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 22 | 107,349 | 98,216 | -1,784 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 73,882 | 65,251 | -34,749 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4,619 | 11,454,774 | 10,449,514 | | 39 | 15 | 5 | 0 | 2 | 7 | 4 | 4 | 4 | 5 | 1 | 5 | 7 |

| Region | Total no. of glut harvests | Run of 2 glut harvests | Run of 3 glut harvests | Run of 4 glut harvests | No. of years of glut within cohorts | | | | | | | | | 39 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 0<br>4,999 | 5,000<br>9,999 | 10,000<br>14,999 | 15,000<br>19,999 | 20,000<br>24,999 | 25,000<br>29,999 | 30,000<br>34,999 | 35,000<br>39,999 | 40,000<br>44,999 | 40,000<br>100,000 |
| Egypt | 39 | 15 | 5 | 0 | 2 | 7 | 4 | 4 | 4 | 5 | 1 | 5 | 7 | |
| Cyprus | 39 | 16 | 6 | 0 | 1 | 4 | 4 | 4 | 4 | 3 | 4 | 3 | 12 | |

| ITERATION 1 | | | | | |
|---|---|---|---|---|---|
| Granaries strategic stock at beginning of the year | 10,197 | | 10,197 | | 10,197 |
| Random generated numers between -50 to +50 | 17 | | 59 | | 50 |
| Total energy available | 70,857 | | 119,661 | | 109,190 |
| Energy to feed 100,000 & remain healthy 106 kcals/yr | 109,190 | 65 | 109,190 | 110 | 109,190 |
| Gross shortfall/surplus | -38,333 | | 10,471 | | 0 |
| Strategy 1: Reduce energy intake | 20,393 | | 0 | | 0 |
| | 0 | | 0 | | 0 |
| Adjusted energy requirement | -17,940 | | 10,471 | | 0 |
| Strat 2: Redistribute granaries strat stock if required | 10,197 | | 0 | | 0 |
| Granary stocks after redistribution | 0 | | 10,197 | | 10,197 |
| Net energy balance | -7,743 | | 10,471 | | 0 |
| Stock up granary | 0 | | 0 | | 0 |
| Availability for redistribution or absorb shortfall | -7,743 | | 10,471 | | 0 |
| Granary stock end of year | 0 | | 10,197 | | 10,197 |
| Net energy at the end of the year | 101,447 | | 119,661 | | 109,190 |
| Seed corn energy shortfall | 0 | | 0 | | 0 |
| Manpower adjustment for seed corn shortfall | 0 | | 0 | | 0 |
| Pop'n/100,000 supported in the current yr | 92,909 | | 109,590 | | 100,000 |
| Shortfall or addit'l workforce that could be supported | -7,091 | | 9,590 | | 0 |
| Egyptian surplus available for added value production | 7,098 | | 23,779 | | 14,189 |

**port 3.44g: Harvest yield only 65% of average yi**

| | | |
|---|---|---|
| Energy to feed 100,000 & remain healthy milliom k | 109,299 | kcal/yr |
| Assume that current harvest yeild was below the av. | 65 | % |
| Energy produced by this poor harvest | 70,857 | kcal/yr |
| Shortfall from average harvest | 38,442 | kcal/yr |
| Strategy 1 reduce ration energy levels by 20% | 20393 | kcal/yr |
| Revised shortfall in energy | 18,049 | kcal/yr |
| Assume strategic buffer is 10% of average harvest y | 10,197 | kcal/yr |
| Strategy 2 empty strategic buffer granaries, revise sh | 7,852 | kcal/yr |
| Resulting energy level after implementing strategies | 101,447 | kcal/yr |
| Size of workforce that can be supported by this redu | 92,816 | |
| Basic needs manpower reqirement | 86,680 | |
| Non basic manpower | 6,136 | |

**Report 3.44h: Average harvest yield**

| | | |
|---|---|---|
| Energy to feed 100,000 & remain healthy milliom k | 109,299 | kcal/yr |
| Assume that current harvest yeild was average | 100 | % |
| Energy produced by this poor harvest | 109,299 | kcal/yr |
| Surplus energy compared with average harvest | 0 | kcal/yr |
| Size of workforce that can be supported | 100,000 | kcal/yr |
| Basic needs manpower reqirement | 86,680 | |
| Non basic manpower | 13,320 | |

**Report 3.44i: Harvest yield 110 % above the average yield**

| | | |
|---|---|---|
| Energy to feed 100,000 & remain healthy milliom k | 109,299 | kcal/yr |
| Assume that current harvest yeild was above the av. | 110 | % |
| Energy produced by this poor harvest | 119,661 | kcal/yr |
| Surplus energy compared with average harvest | 10,362 | kcal/yr |
| Size of workforce that can be supported | 109,480 | kcal/yr |
| Basic needs manpower reqirement | 86,680 | |
| Non basic manpower | 22,800 | |

# Famine and Glut

# Cyprus

**Report 3.45a: Variation in yields due to variation in Nile inundation**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Total energy requirements of 100000 people | 86,065 | Million kcals | | | | | |
| Yield Cyprus for barley on marginal, average, best | 408 | 660 | 1,021 | kg/ha | | | |
| Yield Cyprus for emmer on marginal, average, best | 399 | 714 | 1,490 | kg/ha | | | |
| Yield Cyprus for pulses on marginal, average, best | 455 | 563 | 800 | kg/ha | | | |
| Yield Egypt for barley on marginal, average, best | 703 | 1,057 | 1,313 | kg/ha | | | |
| Yield Egypt for emmer on marginal, average, best | 687 | 1,156 | 1,395 | kg/ha | | | |
| Yield Egypt for pulses on marginal, average, best | 917 | 1,582 | 1,781 | kg/ha | | | |
| Sowing rate | 1 to 10 | 10 | % | | | | |
| Total area Cyprus grain/pulses ploughing/hoeing case | 69,342 | 69,342 | ha | | Food+fodder | 79,360 | 70,415 |
| Total area Cyprus fodder ploughing/hoeing case | 10,018 | 1,073 | ha | | | | |
| Total area Egypt grain/pulses ploughing/hoeing case | 37,834 | 37,834 | ha | | Food+fodder | 59,659 | 39,981 |
| Total area Egypt fodder ploughing/hoeing case | 21,825 | 2,147 | ha | | | | |
| Total agrarian man-years Cyprus ploughing/hoeing | 43,938 | 52,817 | man-years | | Assume 60-40% split ploughing/h | | 47,490 |
| Total agrarian man-years Egypt ploughing/hoeing | 36,298 | 37,593 | man-years | | Assume 30-70% split ploughing/h | | 37,205 |
| Non-agrarian population dry-farming | 56,062 | 47,183 | man-years | | Assume 60-40% split ploughing/h | | 52,510 |
| Non-agrarian population Egypt | 63,702 | 62,407 | man-years | | Assume 30-70% split ploughing/h | | 62,796 |
| Non-productive children and aged | 30,860 | 30,860 | man-years | | | | |
| Surplus for Cyprus farming ploughing/hoeing case | 25,202 | 16,323 | man-years | | Assume 60-40% split ploughing/h | | 21,650 |
| Surplus for Egypt ploughing/hoeing case | 32,842 | 31,547 | man-years | | Assume 70-30% split ploughing/h | | 31,936 |

| Region | Egypt | Cyprus |
|---|---|---|
| Population sample | **100,000** | **100,000** |
| Domestic shelter to satisfy popl'n growth | 920 | 920 |
| Domestic pottery | 66 | 66 |
| Less agrarian workforce | 37,205 | 47,490 |
| Less non-productive 55+ & under 6 | 30,860 | 30,860 |
| Less cloth workforce | 14,659 | 10,430 |
| Less elite | 2,970 | 2,970 |
| **Total non-agrarian workforce** | **13,320** | **7,264** |
| **Non value add workforce** | **86,680** | **92,736** |
| Seed corn grain | 10 | |
| Seed corn pulses | 10 | |

**Report 3.45a2: Energy required to feed 100,000 population + 10% seed corn and 15% wastage**

| | | | |
|---|---|---|---|
| Agrarian energy requirement to maintain healthy population million kcals/yr | 79,697 | Energy provided by protein, dairy, fats etc. | 6,363 |
| Seed corn energy | **19,848** | | |
| Total energy requirement to maintain healthy population less seed corn for grain/pulses | **99,545** | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Random variation around the mean | 100 | 11 | 79 | 96 | 47 | 4 | 63 | 4 | 15 | 46 |

| | |
|---|---|
| **Energy Million kcals/100,000 sample population** | **Average for Cyprus** |
| **Energy of the grain, pulses, olive oil, wine grown + seed corn + protein & dairy** | **95,984** |
| **Energy of the seed corn** | **19848** |
| Agrarian energy requirement to maintain healthy pop'n million kcals/yr | **79,697** |

| | | |
|---|---|---|
| % | **Energy stored** | |

**Report 3.45a3: Average yields from ethnographic data**

| Crop | Yield kg/ha marg'l land | Yield kg/ha av. land | Yield kg/ha best land |
|---|---|---|---|
| Barley | 408 | 660 | 1,073 |
| Wheat | 399 | 714 | 1,455 |
| Pulses | 455 | 563 | 802 |
| Olive Oil | 181 | 272 | 398 |
| Wine | 1,753 | 2,921 | 4,382 |

**Report 3.45a4: Best yield case for famine and glut analysis**

| Crop | Yield kg/ha marg'l land | Yield kg/ha av. land | Yield kg/ha best land |
|---|---|---|---|
| Barley | 510 | 825 | 1,342 |
| Wheat | 499 | 893 | 1,819 |
| Pulses | 546 | 676 | 963 |
| Olive Oil | 209 | 313 | 458 |
| Wine | 1,753 | 2,921 | 4,382 |

**Report 3.44a5: Worst yield case for famine and glut analysis**

| Crop | Yield kg/ha marg'l land | Yield kg/ha av. land | Yield kg/ha best land |
|---|---|---|---|
| Barley | 41 | 330 | 752 |
| Wheat | 40 | 357 | 1,019 |
| Pulses | 46 | 282 | 482 |
| Olive Oil | 37 | 136 | 239 |
| Wine | 0 | 2,045 | 3,067 |

| | | |
|---|---|---|
| Density of barley | 609 | kg/m3 |
| Density of wheat | 769 | kg/m3 |
| Density of pulses | 500 | kg/m3 |

| | |
|---|---|
| Tot energy requirement less seed/wastage to maintain healthy population | **86,060** |
| Total energy required + seed corn +wastage | **105,908** |

**Seed corn manpower assuming 50% ploughing and 50% hoeing**

| | | |
|---|---|---|
| Cyprus | 2,546 | 3,272 |
| Egypt | 2,188 | 2,502 |

| | **Average** |
|---|---|
| Cyprus | 2,909 |
| Egypt | 2,345 |

Report 3.45b: CASE 1a CYPRUS

| % energy decrease in calories for harvest shortfalls | 20 | 15939 | million kcals/yr |
|---|---|---|---|
| Energy stored in granaries | 10 | 7970 | million kcals/yr |

| ITERATION 1 | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 | Year 6 | Year 7 | Year 8 | Year 9 | Year 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Granaries strategic stock at beginning of the year | 7970 | 7,970 | 0 | 7,970 | 7,970 | 7,970 | 7,970 | 7,970 | 7,970 | 3,904 |
| Random generated numers between -50 to +50 | 55 | 30 | 88 | 41 | 42 | 75 | 89 | 88 | 35 | 42 |
| Total energy available | 112,563 | 79,238 | 156,552 | 93,901 | 95,234 | 139,223 | 157,885 | 156,552 | 85,903 | 95,234 |
| Energy to feed 100,000 & remain healthy 106 kcals/yr | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 |
| Gross shortfall/surplus | 6,655 | -26,670 | 50,644 | -12,007 | -10,674 | 33,315 | 51,977 | 50,644 | -20,005 | -10,674 |
| Strategy 1: Reduce energy intake | 0 | 15,939 | 0 | 0 | 0 | 0 | 0 | 0 | 15,939 | 0 |
| | 0 | 0 | 0 | 12,007 | 10,674 | 0 | 0 | 0 | 0 | 10,674 |
| Adjusted energy requirement | 6,655 | -10,731 | 50,644 | 0 | 0 | 33,315 | 51,977 | 50,644 | -4,066 | 0 |
| Strat 2: Redistribute granaries strat stock if required | 0 | 7,970 | 0 | 0 | 0 | 0 | 0 | 0 | 4,066 | 0 |
| Granary stocks after redistribution | 7,970 | 0 | 0 | 7,970 | 7,970 | 7,970 | 7,970 | 7,970 | 3,904 | 3,904 |
| Net energy balance | 6,655 | -2,761 | 50,644 | 0 | 0 | 33,315 | 51,977 | 50,644 | 0 | 0 |
| Stock up granary | 0 | 0 | 7,970 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Availability for redistribution or absorb shortfall | 6,655 | -2,761 | 42,674 | 0 | 0 | 33,315 | 51,977 | 50,644 | 0 | 0 |
| Granary stock end of year | 7,970 | 0 | 7,970 | 7,970 | 7,970 | 7,970 | 7,970 | 7,970 | 3,904 | 3,904 |
| Net energy at the end of the year | 112,563 | 103,147 | 148,582 | 105,908 | 105,908 | 139,223 | 157,885 | 156,552 | 105,908 | 105,908 |
| Seed corn energy shortfall | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Manpower adjustment for seed corn shortfall | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Pop'n/100,000 supported in the current yr | 106,284 | 97,393 | 140,293 | 100,000 | 100,000 | 131,457 | 149,078 | 147,819 | 100,000 | 100,000 |
| Shortfall or addit'l workforce that could be supported | 6,284 | -2,607 | 40,293 | 0 | 0 | 31,457 | 49,078 | 47,819 | 0 | 0 |
| Cypriot surplus available for added value production | 13,548 | 4,657 | 47,557 | 7,264 | 7,264 | 38,721 | 56,342 | 55,083 | 7,264 | 7,264 |

| ITERATION 2 | Year 11 | Year 12 | Year 13 | Year 14 | Year 15 | Year 16 | Year 17 | Year 18 | Year 19 | Year 20 |
|---|---|---|---|---|---|---|---|---|---|---|
| Granaries strategic stock at beginning of the year | 3,904 | 0 | 7,970 | 7,970 | 0 | 0 | 0 | 6,655 | 0 | 0 |
| Random generated numers between -50 to +50 | 9 | 79 | 69 | 23 | 50 | 10 | 55 | 13 | 11 | 27 |
| Total energy available | 51,245 | 144,555 | 131,225 | 69,907 | 105,898 | 52,578 | 112,563 | 56,577 | 53,911 | 75,239 |
| Energy to feed 100,000 & remain healthy 106 kcals/yr | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 |
| Gross shortfall/surplus | -54,663 | 38,647 | 25,317 | -36,001 | -10 | -53,330 | 6,655 | -49,331 | -51,997 | -30,669 |
| Strategy 1: Reduce energy intake | 15,939 | 0 | 0 | 15,939 | 0 | 15,939 | 0 | 15,939 | 15,939 | 15,939 |
| | 0 | 0 | 0 | 0 | 10 | 0 | 0 | 0 | 0 | 0 |
| Adjusted energy requirement | -38,724 | 38,647 | 25,317 | -20,062 | 0 | -37,391 | 6,655 | -33,392 | -36,058 | -14,730 |
| Strat 2: Redistribute granaries strat stock if required | 3,904 | 0 | 0 | 7,970 | 0 | 0 | 0 | 6,655 | 0 | 0 |
| Granary stocks after redistribution | 0 | 0 | 7,970 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Net energy balance | -34,820 | 38,647 | 25,317 | -12,092 | 0 | -37,391 | 6,655 | -26,737 | -36,058 | -14,730 |
| Stock up granary | 0 | 7,970 | 0 | 0 | 0 | 0 | 6,655 | 0 | 0 | 0 |
| Availability for redistribution or absorb shortfall | -34,820 | 30,677 | 25,317 | -12,092 | 0 | -37,391 | 0 | -26,737 | -36,058 | -14,730 |
| Granary stock end of year | 0 | 7,970 | 7,970 | 0 | 0 | 0 | 6,655 | 0 | 0 | 0 |
| Net energy at the end of the year | 71,088 | 136,585 | 131,225 | 93,816 | 105,908 | 68,517 | 105,908 | 79,171 | 69,850 | 91,178 |
| Seed corn energy shortfall | -19,848 | 0 | 0 | -2,168 | 0 | -19,848 | 0 | -16,813 | -19,848 | -4,806 |
| Manpower adjustment for seed corn shortfall | -2,345 | 0 | 0 | -256 | 0 | -2,345 | 0 | -1,986 | -2,345 | -568 |
| Pop'n/100,000 supported in the current yr | 64,777 | 128,966 | 123,905 | 88,327 | 100,000 | 62,350 | 100,000 | 72,769 | 63,608 | 85,524 |
| Shortfall or addit'l workforce that could be supported | -35,223 | 28,966 | 23,905 | -11,673 | 0 | -37,650 | 0 | -27,231 | -36,392 | -14,476 |
| Cypriot surplus available for added value production | 0 | 36,230 | 31,169 | 0 | 7,264 | 0 | 7,264 | 0 | 0 | 0 |

| ITERATION 3 | Year 21 | Year 22 | Year 23 | Year 24 | Year 25 | Year 26 | Year 27 | Year 28 | Year 29 | Year 30 |
|---|---|---|---|---|---|---|---|---|---|---|
| Granaries strategic stock at beginning of the year | 0 | 7,970 | 7,970 | 7,970 | 0 | 7,970 | 7,970 | 7,970 | 7,970 | 7,970 |
| Random generated numers between -50 to +50 | 63 | 67 | 71 | 10 | 77 | 45 | 91 | 87 | 65 | 25 |
| Total energy available | 123,227 | 128,559 | 133,891 | 52,578 | 141,889 | 99,233 | 160,551 | 155,219 | 125,893 | 72,573 |
| Energy to feed 100,000 & remain healthy 106 kcals/yr | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 |
| Gross shortfall/surplus | 17,319 | 22,651 | 27,983 | -53,330 | 35,981 | -6,675 | 54,643 | 49,311 | 19,985 | -33,335 |
| Strategy 1: Reduce energy intake | 0 | 0 | 0 | 15,939 | 0 | 0 | 0 | 0 | 0 | 15,939 |
| | 0 | 0 | 0 | 0 | 0 | 6,675 | 0 | 0 | 0 | 0 |
| Adjusted energy requirement | 17,319 | 22,651 | 27,983 | -37,391 | 35,981 | 0 | 54,643 | 49,311 | 19,985 | -17,396 |
| Strat 2: Redistribute granaries strat stock if required | 0 | 0 | 0 | 7,970 | 0 | 0 | 0 | 0 | 0 | 7,970 |
| Granary stocks after redistribution | 0 | 7,970 | 7,970 | 0 | 0 | 7,970 | 7,970 | 7,970 | 7,970 | 0 |
| Net energy balance | 17,319 | 22,651 | 27,983 | -29,421 | 35,981 | 0 | 54,643 | 49,311 | 19,985 | -9,426 |
| Stock up granary | 7,970 | 0 | 0 | 0 | 7,970 | 0 | 0 | 0 | 0 | 0 |
| Availability for redistribution or absorb shortfall | 9,349 | 22,651 | 27,983 | -29,421 | 28,011 | 0 | 54,643 | 49,311 | 19,985 | -9,426 |
| Granary stock end of year | 7,970 | 7,970 | 7,970 | 0 | 7,970 | 7,970 | 7,970 | 7,970 | 7,970 | 0 |
| Net energy at the end of the year | 115,257 | 128,559 | 133,891 | 76,487 | 133,919 | 105,908 | 160,551 | 155,219 | 125,893 | 96,482 |
| Seed corn energy shortfall | 0 | 0 | 0 | -19,497 | 0 | 0 | 0 | 0 | 0 | 0 |
| Manpower adjustment for seed corn shortfall | 0 | 0 | 0 | -2,304 | 0 | 0 | 0 | 0 | 0 | 0 |
| Pop'n/100,000 supported in the current yr | 108,827 | 121,387 | 126,422 | 69,916 | 126,448 | 100,000 | 151,595 | 146,560 | 118,870 | 91,100 |
| Shortfall or addit'l workforce that could be supported | 8,827 | 21,387 | 26,422 | -30,084 | 26,448 | 0 | 51,595 | 46,560 | 18,870 | -8,900 |
| Cypriot surplus available for added value production | 16,091 | 28,651 | 33,686 | 0 | 33,712 | 7,264 | 58,859 | 53,824 | 26,134 | 0 |

| ITERATION 4 | Year 31 | Year 32 | Year 33 | Year 34 | Year 35 | Year 36 | Year 37 | Year 38 | Year 39 | Year 40 |
|---|---|---|---|---|---|---|---|---|---|---|
| Granaries strategic stock at beginning of the year | 0 | 7,970 | 7,970 | 0 | 0 | 7,970 | 0 | 0 | 0 | 7,970 |
| Random generated numers between -50 to +50 | 87 | 74 | 26 | 14 | 84 | 27 | 15 | 38 | 100 | 38 |
| Total energy available | 155,219 | 137,890 | 73,906 | 57,910 | 151,220 | 75,239 | 59,243 | 89,902 | 172,548 | 89,902 |
| Energy to feed 100,000 & remain healthy 106 kcals/yr | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 |
| Gross shortfall/surplus | 49,311 | 31,982 | -32,002 | -47,998 | 45,312 | -30,669 | -46,665 | -16,006 | 66,640 | -16,006 |
| Strategy 1: Reduce energy intake | 0 | 0 | 15,939 | 15,939 | 0 | 15,939 | 15,939 | 15,939 | 0 | 15,939 |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Adjusted energy requirement | 49,311 | 31,982 | -16,063 | -32,059 | 45,312 | -14,730 | -30,726 | -67 | 66,640 | -67 |
| Strat 2: Redistribute granaries strat stock if required | 0 | 0 | 7,970 | 0 | 0 | 7,970 | 0 | 0 | 0 | 67 |
| Granary stocks after redistribution | 0 | 7,970 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7,903 |
| Net energy balance | 49,311 | 31,982 | -8,093 | -32,059 | 45,312 | -6,760 | -30,726 | -67 | 66,640 | 0 |
| Stock up granary | 7,970 | 0 | 0 | 0 | 7,970 | 0 | 0 | 0 | 7,970 | 0 |
| Availability for redistribution or absorb shortfall | 41,341 | 31,982 | -8,093 | -32,059 | 37,342 | -6,760 | -30,726 | -67 | 58,670 | 0 |
| Granary stock end of year | 7,970 | 7,970 | 0 | 0 | 7,970 | 0 | 0 | 0 | 7,970 | 7,903 |
| Net energy at the end of the year | 147,249 | 137,890 | 97,815 | 73,849 | 143,250 | 99,148 | 75,182 | 105,841 | 164,578 | 105,908 |
| Seed corn energy shortfall | 0 | 0 | 0 | -19,848 | 0 | 0 | -19,848 | 0 | 0 | 0 |
| Manpower adjustment for seed corn shortfall | 0 | 0 | 0 | -2,345 | 0 | 0 | -2,345 | 0 | 0 | 0 |
| Pop'n/100,000 supported in the current yr | 139,035 | 130,198 | 92,358 | 67,384 | 135,259 | 93,617 | 68,643 | 99,937 | 155,397 | 100,000 |
| Shortfall or addit'l workforce that could be supported | 39,035 | 30,198 | -7,642 | -32,616 | 35,259 | -6,383 | -31,357 | -63 | 55,397 | 0 |
| Cypriot surplus available for added value production | 46,299 | 37,462 | 0 | 0 | 42,523 | 881 | 0 | 7,201 | 62,661 | 7,264 |

| ITERATION 5 | Year 41 | Year 42 | Year 43 | Year 44 | Year 45 | Year 46 | Year 47 | Year 48 | Year 49 | Year 50 |
|---|---|---|---|---|---|---|---|---|---|---|
| Granaries strategic stock at beginning of the year | 7,903 | 0 | 0 | 0 | 0 | 0 | 0 | 7,970 | 7,970 | 0 |
| Random generated numers between -50 to +50 | 20 | 45 | 8 | 50 | 2 | 6 | 80 | 97 | 22 | 29 |
| Total energy available | 65,908 | 99,233 | 49,912 | 105,898 | 41,914 | 47,246 | 145,888 | 168,549 | 68,574 | 77,905 |
| Energy to feed 100,000 & remain healthy 106 kcals/yr | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 |
| Gross shortfall/surplus | -40,000 | -6,675 | -55,996 | -10 | -63,994 | -58,662 | 39,980 | 62,641 | -37,334 | -28,003 |
| Strategy 1: Reduce energy intake | 15,939 | 0 | 15,939 | 0 | 15,939 | 15,939 | 0 | 0 | 15,939 | 15,939 |
| | 0 | 6,675 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 0 |
| Adjusted energy requirement | -24,061 | 0 | -40,057 | 0 | -48,055 | -42,723 | 39,980 | 62,641 | -21,395 | -12,064 |
| Strat 2: Redistribute granaries strat stock if required | 7,903 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7,970 | 0 |
| Granary stocks after redistribution | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7,970 | 0 | 0 |
| Net energy balance | -16,158 | 0 | -40,057 | 0 | -48,055 | -42,723 | 39,980 | 62,641 | -13,425 | -12,064 |
| Stock up granary | 0 | 0 | 0 | 0 | 0 | 0 | 7,970 | 0 | 0 | 0 |
| Availability for redistribution or absorb shortfall | -16,158 | 0 | -40,057 | 0 | -48,055 | -42,723 | 32,010 | 62,641 | -13,425 | -12,064 |
| Granary stock end of year | 0 | 0 | 0 | 0 | 0 | 0 | 7,970 | 7,970 | 0 | 0 |
| Net energy at the end of the year | 89,750 | 105,908 | 65,851 | 105,908 | 57,853 | 63,185 | 137,918 | 168,549 | 92,483 | 93,844 |
| Seed corn energy shortfall | -6,234 | 0 | -19,848 | 0 | -19,848 | -19,848 | 0 | 0 | -3,501 | -2,140 |
| Manpower adjustment for seed corn shortfall | -737 | 0 | -2,345 | 0 | -2,345 | -2,345 | 0 | 0 | -414 | -253 |
| Pop'n/100,000 supported in the current yr | 84,006 | 100,000 | 59,833 | 100,000 | 52,281 | 57,315 | 130,224 | 159,147 | 86,910 | 88,356 |
| Shortfall or addit'l workforce that could be supported | -15,994 | 0 | -40,167 | 0 | -47,719 | -42,685 | 30,224 | 59,147 | -13,090 | -11,644 |
| Cypriot surplus available for added value production | 0 | 7,264 | 0 | 7,264 | 0 | 0 | 37,488 | 66,411 | 0 | 0 |

| ITERATION 6 | Year 51 | Year 52 | Year 53 | Year 54 | Year 55 | Year 56 | Year 57 | Year 58 | Year 59 | Year 60 |
|---|---|---|---|---|---|---|---|---|---|---|
| Granaries strategic stock at beginning of the year | 0 | 0 | 7,970 | 7,970 | 0 | 0 | 0 | 7,970 | 0 | 0 |
| Random generated numers between -50 to +50 | 44 | 65 | 60 | 9 | 14 | 48 | 68 | 6 | 30 | 72 |
| Total energy available | 97,900 | 125,893 | 119,228 | 51,245 | 57,910 | 103,232 | 129,892 | 47,246 | 79,238 | 135,224 |
| Energy to feed 100,000 & remain healthy 106 kcals/yr | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 |
| Gross shortfall/surplus | -8,008 | 19,985 | 13,320 | -54,663 | -47,998 | -2,676 | 23,984 | -58,662 | -26,670 | 29,316 |
| Strategy 1: Reduce energy intake | 0 | 0 | 0 | 15,939 | 15,939 | 0 | 0 | 15,939 | 15,939 | 0 |
| | 8,008 | 0 | 0 | 0 | 0 | 2,676 | 0 | 0 | 0 | 0 |
| Adjusted energy requirement | 0 | 19,985 | 13,320 | -38,724 | -32,059 | 0 | 23,984 | -42,723 | -10,731 | 29,316 |
| Strat 2: Redistribute granaries strat stock if required | 0 | 0 | 0 | 7,970 | 0 | 0 | 0 | 7,970 | 0 | 0 |
| Granary stocks after redistribution | 0 | 0 | 7,970 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Net energy balance | 0 | 19,985 | 13,320 | -30,754 | -32,059 | 0 | 23,984 | -34,753 | -10,731 | 29,316 |
| Stock up granary | 0 | 7,970 | 0 | 0 | 0 | 0 | 7,970 | 0 | 0 | 7,970 |
| Availability for redistribution or absorb shortfall | 0 | 12,015 | 13,320 | -30,754 | -32,059 | 0 | 16,014 | -34,753 | -10,731 | 21,346 |
| Granary stock end of year | 0 | 7,970 | 7,970 | 0 | 0 | 0 | 7,970 | 0 | 0 | 7,970 |
| Net energy at the end of the year | 105,908 | 117,923 | 119,228 | 75,154 | 73,849 | 105,908 | 121,922 | 71,155 | 95,177 | 127,254 |
| Seed corn energy shortfall | 0 | 0 | 0 | -19,848 | -19,848 | 0 | 0 | -19,848 | -807 | 0 |
| Manpower adjustment for seed corn shortfall | 0 | 0 | 0 | -2,345 | -2,345 | 0 | 0 | -2,345 | -95 | 0 |
| Pop'n/100,000 supported in the current yr | 100,000 | 111,345 | 112,577 | 68,617 | 67,384 | 100,000 | 115,121 | 64,841 | 89,773 | 120,155 |
| Shortfall or addit'l workforce that could be supported | 0 | 11,345 | 12,577 | -31,383 | -32,616 | 0 | 15,121 | -35,159 | -10,227 | 20,155 |
| Cypriot surplus available for added value production | 7,264 | 18,609 | 19,841 | 0 | 0 | 7,264 | 22,385 | 0 | 0 | 27,419 |

| ITERATION 7 | Year 61 | Year 62 | Year 63 | Year 64 | Year 65 | Year 66 | Year 67 | Year 68 | Year 69 | Year 70 |
|---|---|---|---|---|---|---|---|---|---|---|
| Granaries strategic stock at beginning of the year | 7,970 | 7,970 | 7,970 | 0 | 7,970 | 7,970 | 7,970 | 0 | 6,655 | 0 |
| Random generated numers between -50 to +50 | 77 | 78 | 15 | 71 | 49 | 44 | 25 | 55 | 13 | 23 |
| Total energy available | 141,889 | 143,222 | 59,243 | 133,891 | 104,565 | 97,900 | 72,573 | 112,563 | 56,577 | 69,907 |
| Energy to feed 100,000 & remain healthy 106 kcals/yr | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 |
| Gross shortfall/surplus | 35,981 | 37,314 | -46,665 | 27,983 | -1,343 | -8,008 | -33,335 | 6,655 | -49,331 | -36,001 |
| Strategy 1: Reduce energy intake | 0 | 0 | 15,939 | 0 | 0 | 0 | 15,939 | 0 | 15,939 | 15,939 |
| | 0 | 0 | 0 | 0 | 1,343 | 8,008 | 0 | 0 | 0 | 0 |
| Adjusted energy requirement | 35,981 | 37,314 | -30,726 | 27,983 | 0 | 0 | -17,396 | 6,655 | -33,392 | -20,062 |
| Strat 2: Redistribute granaries strat stock if required | 0 | 0 | 7,970 | 0 | 0 | 0 | 7,970 | 0 | 6,655 | 0 |
| Granary stocks after redistribution | 7,970 | 7,970 | 0 | 0 | 7,970 | 7,970 | 0 | 0 | 0 | 0 |
| Net energy balance | 35,981 | 37,314 | -22,756 | 27,983 | 0 | 0 | -9,426 | 6,655 | -26,737 | -20,062 |
| Stock up granary | 0 | 0 | 0 | 7,970 | 0 | 0 | 0 | 6,655 | 0 | 0 |
| Availability for redistribution or absorb shortfall | 35,981 | 37,314 | -22,756 | 20,013 | 0 | 0 | -9,426 | 0 | -26,737 | -20,062 |
| Granary stock end of year | 7,970 | 7,970 | 0 | 7,970 | 7,970 | 7,970 | 0 | 6,655 | 0 | 0 |
| Net energy at the end of the year | 141,889 | 143,222 | 83,152 | 125,921 | 105,908 | 105,908 | 96,482 | 105,908 | 79,171 | 85,846 |
| Seed corn energy shortfall | 0 | 0 | -12,832 | 0 | 0 | 0 | 0 | 0 | -16,813 | -10,138 |
| Manpower adjustment for seed corn shortfall | 0 | 0 | -1,516 | 0 | 0 | 0 | 0 | 0 | -1,986 | -1,198 |
| Pop'n/100,000 supported in the current yr | 133,974 | 135,232 | 76,997 | 118,897 | 100,000 | 100,000 | 91,100 | 100,000 | 72,769 | 79,859 |
| Shortfall or addit'l workforce that could be supported | 33,974 | 35,232 | -23,003 | 18,897 | 0 | 0 | -8,900 | 0 | -27,231 | -20,141 |
| Cypriot surplus available for added value production | 41,238 | 42,496 | 0 | 26,161 | 7,264 | 7,264 | 0 | 7,264 | 0 | 0 |

| ITERATION 8 | Year 71 | Year 72 | Year 73 | Year 74 | Year 75 | Year 76 | Year 77 | Year 78 | Year 79 | Year 80 |
|---|---|---|---|---|---|---|---|---|---|---|
| Granaries strategic stock at beginning of the year | 0 | 7,970 | 7,970 | 7,970 | 7,970 | 7,970 | 7,970 | 7,970 | 7,970 | 7,970 |
| Random generated numers between -50 to +50 | 57 | 66 | 63 | 43 | 56 | 87 | 88 | 46 | 56 | 14 |
| Total energy available | 115,229 | 127,226 | 123,227 | 96,567 | 113,896 | 155,219 | 156,552 | 100,566 | 113,896 | 57,910 |
| Energy to feed 100,000 & remain healthy 106 kcals/yr | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 |
| Gross shortfall/surplus | 9,321 | 21,318 | 17,319 | -9,341 | 7,988 | 49,311 | 50,644 | -5,342 | 7,988 | -47,998 |
| Strategy 1: Reduce energy intake | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 15,939 |
| | 0 | 0 | 0 | 9,341 | 0 | 0 | 0 | 5,342 | 0 | 0 |
| Adjusted energy requirement | 9,321 | 21,318 | 17,319 | 0 | 7,988 | 49,311 | 50,644 | 0 | 7,988 | -32,059 |
| Strat 2: Redistribute granaries strat stock if required | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7,970 |
| Granary stocks after redistribution | 0 | 7,970 | 7,970 | 7,970 | 7,970 | 7,970 | 7,970 | 7,970 | 7,970 | 0 |
| Net energy balance | 9,321 | 21,318 | 17,319 | 0 | 7,988 | 49,311 | 50,644 | 0 | 7,988 | -24,089 |
| Stock up granary | 7,970 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Availability for redistribution or absorb shortfall | 1,351 | 21,318 | 17,319 | 0 | 7,988 | 49,311 | 50,644 | 0 | 7,988 | -24,089 |
| Granary stock end of year | 7,970 | 7,970 | 7,970 | 7,970 | 7,970 | 7,970 | 7,970 | 7,970 | 7,970 | 0 |
| Net energy at the end of the year | 107,259 | 127,226 | 123,227 | 105,908 | 113,896 | 155,219 | 156,552 | 105,908 | 113,896 | 81,819 |
| Seed corn energy shortfall | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -14,165 |
| Manpower adjustment for seed corn shortfall | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1,674 |
| Pop'n/100,000 supported in the current yr | 101,276 | 120,129 | 116,353 | 100,000 | 107,542 | 146,560 | 147,819 | 100,000 | 107,542 | 75,581 |
| Shortfall or addit'l workforce that could be supported | 1,276 | 20,129 | 16,353 | 0 | 7,542 | 46,560 | 47,819 | 0 | 7,542 | -24,419 |
| Cypriot surplus available for added value production | 8,540 | 27,393 | 23,617 | 7,264 | 14,806 | 53,824 | 55,083 | 7,264 | 14,806 | 0 |

| ITERATION 9 | Year 81 | Year 82 | Year 83 | Year 84 | Year 85 | Year 86 | Year 87 | Year 88 | Year 89 | Year 90 |
|---|---|---|---|---|---|---|---|---|---|---|
| Granaries strategic stock at beginning of the year | 0 | 7,970 | 0 | 7,970 | 0 | 7,970 | 1,238 | 0 | 0 | 0 |
| Random generated numers between -50 to +50 | 67 | 27 | 97 | 23 | 66 | 33 | 35 | 14 | 9 | 39 |
| Total energy available | 128,559 | 75,239 | 168,549 | 69,907 | 127,226 | 83,237 | 85,903 | 57,910 | 51,245 | 91,235 |
| Energy to feed 100,000 & remain healthy 106 kcals/yr | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 |
| Gross shortfall/surplus | 22,651 | -30,669 | 62,641 | -36,001 | 21,318 | -22,671 | -20,005 | -47,998 | -54,663 | -14,673 |
| Strategy 1: Reduce energy intake | 0 | 15,939 | 0 | 15,939 | 0 | 15,939 | 15,939 | 15,939 | 15,939 | 0 |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 14,673 |
| Adjusted energy requirement | 22,651 | -14,730 | 62,641 | -20,062 | 21,318 | -6,732 | -4,066 | -32,059 | -38,724 | 0 |
| Strat 2: Redistribute granaries strat stock if required | 0 | 7,970 | 0 | 7,970 | 0 | 6,732 | 1,238 | 0 | 0 | 0 |
| Granary stocks after redistribution | 0 | 0 | 0 | 0 | 0 | 1,238 | 0 | 0 | 0 | 0 |
| Net energy balance | 22,651 | -6,760 | 62,641 | -12,092 | 21,318 | 0 | -2,828 | -32,059 | -38,724 | 0 |
| Stock up granary | 7,970 | 0 | 7,970 | 0 | 7,970 | 0 | 0 | 0 | 0 | 0 |
| Availability for redistribution or absorb shortfall | 14,681 | -6,760 | 54,671 | -12,092 | 13,348 | 0 | -2,828 | -32,059 | -38,724 | 0 |
| Granary stock end of year | 7,970 | 0 | 7,970 | 0 | 7,970 | 1,238 | 0 | 0 | 0 | 0 |
| Net energy at the end of the year | 120,589 | 99,148 | 160,579 | 93,816 | 119,256 | 105,908 | 103,080 | 73,849 | 67,184 | 105,908 |
| Seed corn energy shortfall | 0 | 0 | 0 | -2,168 | 0 | 0 | 0 | -19,848 | -19,848 | 0 |
| Manpower adjustment for seed corn shortfall | 0 | 0 | 0 | -256 | 0 | 0 | 0 | -2,345 | -2,345 | 0 |
| Pop'n/100,000 supported in the current yr | 113,862 | 93,617 | 151,621 | 88,327 | 112,603 | 100,000 | 97,330 | 67,384 | 61,091 | 100,000 |
| Shortfall or addit'l workforce that could be supported | 13,862 | -6,383 | 51,621 | -11,673 | 12,603 | 0 | -2,670 | -32,616 | -38,909 | 0 |
| Cypriot surplus available for added value production | 21,126 | 881 | 58,885 | 0 | 19,867 | 7,264 | 4,594 | 0 | 0 | 7,264 |

| ITERATION 10 | Year 91 | Year 92 | Year 93 | Year 94 | Year 95 | Year 96 | Year 97 | Year 98 | Year 99 | Year 100 |
|---|---|---|---|---|---|---|---|---|---|---|
| Granaries strategic stock at beginning of the year | 0 | 7,970 | 0 | 0 | 0 | 0 | 0 | 7,970 | 7,903 | 0 |
| Random generated numers between -50 to +50 | 95 | 18 | 26 | 20 | 8 | 48 | 96 | 38 | 22 | 2 |
| Total energy available | 165,883 | 63,242 | 73,906 | 65,908 | 49,912 | 103,232 | 167,216 | 89,902 | 68,574 | 41,914 |
| Energy to feed 100,000 & remain healthy 106 kcals/yr | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 | 105,908 |
| Gross shortfall/surplus | 59,975 | -42,666 | -32,002 | -40,000 | -55,996 | -2,676 | 61,308 | -16,006 | -37,334 | -63,994 |
| Strategy 1: Reduce energy intake | 0 | 15,939 | 15,939 | 15,939 | 15,939 | 0 | 0 | 15,939 | 15,939 | 15,939 |
| | 0 | 0 | 0 | 0 | 0 | 2,676 | 0 | 0 | 0 | 0 |
| Adjusted energy requirement | 59,975 | -26,727 | -16,063 | -24,061 | -40,057 | 0 | 61,308 | -67 | -21,395 | -48,055 |
| Strat 2: Redistribute granaries strat stock if required | 0 | 7,970 | 0 | 0 | 0 | 0 | 0 | 67 | 7,903 | 0 |
| Granary stocks after redistribution | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7,903 | 0 | 0 |
| Net energy balance | 59,975 | -18,757 | -16,063 | -24,061 | -40,057 | 0 | 61,308 | 0 | -13,492 | -48,055 |
| Stock up granary | 7,970 | 0 | 0 | 0 | 0 | 0 | 7,970 | 0 | 0 | 0 |
| Availability for redistribution or absorb shortfall | 52,005 | -18,757 | -16,063 | -24,061 | -40,057 | 0 | 53,338 | 0 | -13,492 | -48,055 |
| Granary stock end of year | 7,970 | 0 | 0 | 0 | 0 | 0 | 7,970 | 7,903 | 0 | 0 |
| Net energy at the end of the year | 157,913 | 87,151 | 89,845 | 81,847 | 65,851 | 105,908 | 159,246 | 105,908 | 92,416 | 57,853 |
| Seed corn energy shortfall | 0 | -8,833 | -6,139 | -14,137 | -19,848 | 0 | 0 | 0 | -3,568 | -19,848 |
| Manpower adjustment for seed corn shortfall | 0 | -1,044 | -725 | -1,670 | -2,345 | 0 | 0 | 0 | -422 | -2,345 |
| Pop'n/100,000 supported in the current yr | 149,104 | 81,245 | 84,108 | 75,611 | 59,833 | 100,000 | 150,363 | 100,000 | 86,839 | 52,281 |
| Shortfall or addit'l workforce that could be supported | 49,104 | -18,755 | -15,892 | -24,389 | -40,167 | 0 | 50,363 | 0 | -13,161 | -47,719 |
| Cypriot surplus available for added value production | 56,368 | 0 | 0 | 0 | 0 | 7,264 | 57,627 | 7,264 | 0 | 0 |

| Iteration | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Min/Max |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Minimum Net energy balance | 79,238 | 51,245 | 52,578 | 57,910 | 41,914 | 47,246 | 56,577 | 57,910 | 51,245 | 41,914 | **41,914** |
| Maximum Net energy balance | 157,885 | 105,908 | 160,551 | 172,548 | 168,549 | 135,224 | 143,222 | 156,552 | 168,549 | 167,216 | **172,548** |

Report 3.45c1: Famine analysis

| Yield variation | Net energy at end of year million after taking into account gains | Population per 100,000 that could be supported in the current | Surplus or unfed manpower | Years where harvest + 20% reduction in rations + strategy failed to maintain 15% buffer in granaries failed to feed all the population | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Unfed manpower | One year | Run of two years | Run of three years | 0 -4,999 | -5,000 -9,999 | -10,000 -14,999 | -15,000 -19,999 | -20,000 -24,999 | -25,000 -29,999 | -30,000 -34,999 | -35,000 -39,999 | -40,000 -44,999 |
| 55 | 112,563 | 106,284 | 6,284 | 0 | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 30 | 103,147 | 97,393 | -2,607 | 1 | 0 | | | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 88 | 148,582 | 140,293 | 40,293 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 41 | 105,908 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 42 | 105,908 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 75 | 139,223 | 131,457 | 31,457 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 89 | 157,885 | 149,078 | 49,078 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 88 | 156,552 | 147,819 | 47,819 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 35 | 105,908 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 42 | 105,908 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 71,088 | 64,777 | -35,223 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 79 | 136,585 | 128,966 | 28,966 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 69 | 131,225 | 123,905 | 23,905 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 23 | 93,816 | 88,327 | -11,673 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 50 | 105,908 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 68,517 | 62,350 | -37,650 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 55 | 105,908 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 13 | 79,171 | 72,769 | -27,231 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 11 | 69,850 | 63,608 | -36,392 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 27 | 91,178 | 85,524 | -14,476 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 63 | 115,257 | 108,827 | 8,827 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 67 | 128,559 | 121,387 | 21,387 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 71 | 133,891 | 126,422 | 26,422 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 76,487 | 69,916 | -30,084 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 77 | 133,919 | 126,448 | 26,448 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 45 | 105,908 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 91 | 160,551 | 151,595 | 51,595 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 87 | 155,219 | 146,560 | 46,560 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 65 | 125,893 | 118,870 | 18,870 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 25 | 96,482 | 91,100 | -8,900 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 87 | 147,249 | 139,035 | 39,035 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 74 | 137,890 | 130,198 | 30,198 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 26 | 97,815 | 92,358 | -7,642 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 14 | 73,849 | 67,384 | -32,616 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 84 | 143,250 | 135,259 | 35,259 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 27 | 99,148 | 93,617 | -6,383 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 15 | 75,182 | 68,643 | -31,357 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 38 | 105,841 | 99,937 | -63 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 100 | 164,578 | 155,397 | 55,397 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 38 | 105,908 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | 89,750 | 84,006 | -15,994 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 45 | 105,908 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 65,851 | 59,833 | -40,167 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

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| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 50 | 105,908 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 57,853 | 52,281 | -47,719 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 63,185 | 57,315 | -42,685 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 80 | 137,918 | 130,224 | 30,224 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 97 | 168,549 | 159,147 | 59,147 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 22 | 92,483 | 86,910 | -13,090 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 29 | 93,844 | 88,356 | -11,644 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 44 | 105,908 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 65 | 117,923 | 111,345 | 11,345 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 60 | 119,228 | 112,577 | 12,577 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 75,154 | 68,617 | -31,383 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 14 | 73,849 | 67,384 | -32,616 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 48 | 105,908 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 68 | 121,922 | 115,121 | 15,121 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 71,155 | 64,841 | -35,159 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 30 | 95,177 | 89,773 | -10,227 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 72 | 127,254 | 120,155 | 20,155 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 77 | 141,889 | 133,974 | 33,974 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 78 | 143,222 | 135,232 | 35,232 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 15 | 83,152 | 76,997 | -23,003 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| 71 | 125,921 | 118,897 | 18,897 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 49 | 105,908 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 44 | 105,908 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 25 | 96,482 | 91,100 | -8,900 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 55 | 105,908 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 13 | 79,171 | 72,769 | -27,231 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 23 | 85,846 | 79,859 | -20,141 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| 57 | 107,259 | 101,276 | 1,276 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 66 | 127,226 | 120,129 | 20,129 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 63 | 123,227 | 116,353 | 16,353 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 43 | 105,908 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 56 | 113,896 | 107,542 | 7,542 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 87 | 155,219 | 146,560 | 46,560 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 88 | 156,552 | 147,819 | 47,819 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 46 | 105,908 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 56 | 113,896 | 107,542 | 7,542 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 14 | 81,819 | 75,581 | -24,419 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| 67 | 120,589 | 113,862 | 13,862 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 27 | 99,148 | 93,617 | -6,383 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 97 | 160,579 | 151,621 | 51,621 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 23 | 93,816 | 88,327 | -11,673 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 66 | 119,256 | 112,603 | 12,603 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 33 | 105,908 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 35 | 103,080 | 97,330 | -2,670 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 14 | 73,849 | 67,384 | -32,616 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 9 | 67,184 | 61,091 | -38,909 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 39 | 105,908 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 95 | 157,913 | 149,104 | 49,104 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 18 | 87,151 | 81,245 | -18,755 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |

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| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 26 | 89,845 | 84,108 | -15,892 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 20 | 81,847 | 75,611 | -24,389 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| 8 | 65,851 | 59,833 | -40,167 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 48 | 105,908 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 96 | 159,246 | 150,363 | 50,363 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 38 | 105,908 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 22 | 92,416 | 86,839 | -13,161 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 57,853 | 52,281 | -47,719 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4,619 | 10,890,005 | 10,230,238 | | 40 | 16 | 5 | 0 | 3 | 5 | 7 | 3 | 4 | 2 | 6 | 5 | 3 |
| Maximum | 168,549 | 159,147 | 59,147 | | | | | | | | | | | | | |
| Minimum | 57,853 | 52,281 | -47,719 | 0 | | | | | | | | | | | | |

**Report 3.45d: Summary of increase buffer levels**

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 40 | 16 | 5 | 0 | 3 | 5 | 7 | 3 | 4 | 2 | 6 | 5 | 3 |
| 20 | 0 | 44 | 19 | 7 | 0 | 5 | 1 | 6 | 4 | 7 | 1 | 8 | 6 | 4 |
| Rations % reduction | Granary buffer % | No. of failed harvests | Run of 2 failed harvests | Run of 3 failed harvests | Run of 4 failed harvests | 0 -4,999 | -5,000 -9,999 | -10,000 -14,999 | -15,000 -19,999 | -20,000 -24,999 | -25,000 -29,999 | -30,000 -34,999 | -35,000 -39,999 | -40,000 -44,999 |
| 20 | 5 | 42 | 17 | 6 | 0 | 4 | 1 | 8 | 5 | 4 | 2 | 7 | 6 | 3 |
| 20 | 10 | 40 | 16 | 5 | 0 | 3 | 5 | 7 | 3 | 4 | 2 | 6 | 5 | 3 |
| | | **40** | **16** | **5** | **0** | **3** | **5** | **7** | **3** | **4** | **2** | **6** | **5** | **3** |
| 20 | 15 | 38 | 15 | 4 | 0 | 4 | 6 | 5 | 2 | 3 | 4 | 6 | 3 | 3 |
| 20 | 20 | 36 | 14 | 3 | 0 | 6 | 3 | 5 | 2 | 4 | 5 | 3 | 3 | 3 |
| 20 | 25 | 33 | 13 | 3 | 0 | 6 | 1 | 5 | 3 | 5 | 4 | 1 | 3 | 3 |

**Report 3.45c: Value add naalysis** Below average but above fame set 1, average set 2, above average set 3 **3**

| Yield variation | Workers per 100,000 that could be supported in current yr | Value add | Years with value add | Run of two years with value add | Run of three years with value add | Run of four years with value add | Years of value add within cohort ranges | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Cohort 0 4,999 | Cohort 5,000 9,999 | Cohort 10,000 14,999 | Cohort 15,000 19,999 | Cohort 20,000 24,999 | Cohort 25,000 29,999 | Cohort 30,000 34,999 | Cohort 35,000 39,999 | Cohort 40,000 100,000 | |
| 55 | 106,284 | 6,284 | 1 | | | | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 30 | 97,393 | 0 | 0 | 0 | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 88 | 140,293 | 40,293 | 1 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| 41 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 42 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 75 | 131,457 | 31,457 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| 89 | 149,078 | 49,078 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| 88 | 147,819 | 47,819 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| 35 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 42 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 64,777 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 79 | 128,966 | 28,966 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| 69 | 123,905 | 23,905 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 23 | 88,327 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 50 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 62,350 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 55 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 13 | 72,769 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | 63,608 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 27 | 85,524 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 63 | 108,827 | 8,827 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 67 | 121,387 | 21,387 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 71 | 126,422 | 26,422 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| 10 | 69,916 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 77 | 126,448 | 26,448 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| 45 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 91 | 151,595 | 51,595 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| 87 | 146,560 | 46,560 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| 65 | 118,870 | 18,870 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| 25 | 91,100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 87 | 139,035 | 39,035 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| 74 | 130,198 | 30,198 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| 26 | 92,358 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 14 | 67,384 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 84 | 135,259 | 35,259 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| 27 | 93,617 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 15 | 68,643 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 38 | 99,937 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 100 | 155,397 | 55,397 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| 38 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | 84,006 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 45 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

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| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8 | 59,833 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 30 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 52,281 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 57,315 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 80 | 130,224 | 30,224 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| 97 | 159,147 | 59,147 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| 22 | 86,910 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 29 | 88,356 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 44 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 65 | 111,345 | 11,345 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 60 | 112,577 | 12,577 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 9 | 68,617 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 14 | 67,384 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 48 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 68 | 115,121 | 15,121 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| 6 | 64,841 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 30 | 89,773 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 72 | 120,155 | 20,155 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 77 | 133,974 | 33,974 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| 78 | 135,232 | 35,232 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| 15 | 76,997 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 71 | 118,897 | 18,897 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| 49 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 44 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 25 | 91,100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 55 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 13 | 72,769 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 23 | 79,859 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 57 | 101,276 | 1,276 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 66 | 120,129 | 20,129 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 63 | 116,353 | 16,353 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| 43 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 56 | 107,542 | 7,542 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 87 | 146,560 | 46,560 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| 88 | 147,819 | 47,819 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| 46 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 56 | 107,542 | 7,542 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 14 | 75,581 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 67 | 113,862 | 13,862 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 27 | 93,617 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 97 | 151,621 | 51,621 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| 23 | 88,327 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 66 | 112,603 | 12,603 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 33 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 35 | 97,330 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 14 | 67,384 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 61,091 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 39 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 95 | 149,104 | 49,104 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |

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| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 18 | 81,245 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 26 | 84,108 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | 75,611 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 59,833 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 48 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 96 | 150,363 | 50,363 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| 38 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 22 | 86,839 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 52,281 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4,619 | 10,230,238 | 1,149,246 | 39 | 16 | 6 | 0 | 1 | 4 | 4 | 4 | 4 | 3 | 4 | 3 | 12 | 39 |
| Yrs with value add production for the case 15% strategic granary stock + 20% reduction in rations | | | | | 72 | | | | | | | | | | 39 | |

| | Rations % reduction | Granary buffer % | Years with value add | Run of two years with value add | Run of three years with value add | Run of four years with value add | Years of value add within cohort ranges: Cohort 0 4,999 | Cohort 5,000 9,999 | Cohort 10,000 14,999 | Cohort 15,000 19,999 | Cohort 20,000 24,999 | Cohort 25,000 29,999 | Cohort 30,000 34,999 | Cohort 35,000 39,999 | Cohort 40,000 100,000 | Total years of value add |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 20 | 5 | 37 | 14 | 3 | 0 | 1 | 21 | 3 | 3 | 3 | 6 | 4 | 3 | 19 | 63 |
| LT av harvests but some added value | | | 6 | 0 | 0 | 0 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 |
| Average harvests | 20 | 10 | 21 | 3 | 0 | 0 | 0 | 21 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 21 |
| Harvests GT than average | | | 39 | 16 | 6 | 0 | 1 | 4 | 4 | 4 | 4 | 3 | 4 | 3 | 12 | 39 |
| | | | | | | | | | | | | | | | | 66 |
| | 20 | 15 | 28 | 10 | 3 | 0 | 6 | 28 | 1 | 6 | 3 | 4 | 4 | 3 | 17 | 72 |
| | 20 | 20 | 27 | 10 | 3 | 0 | 3 | 32 | 3 | 5 | 4 | 3 | 4 | 3 | 16 | 73 |
| | 20 | 25 | 26 | 9 | 2 | 0 | 1 | 36 | 4 | 6 | 2 | 5 | 2 | 3 | 15 | 74 |

**Report 3.45c2 : Below, average, and above average analysis on the manpower available for non-basic activities**

| | | | Below average harvests | | Average harvests | | Above average harvests | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Yield variation | Workers per 100,000 that could be supported in current yr | Workers per 100,000 that could be supported in current yr | Value add | Workers per 100,000 that could be supported in current yr | Value add | Workers per 100,000 that could be supported in current yr | Value add | | No. of years where no value add can be supported |
| 1 | 55 | 106,284 | 0 | 0 | 0 | 0 | 6,284 | 1 | 1 | 0 |
| 2 | 30 | 97,393 | 6,163 | 1 | 0 | 0 | 0 | 0 | 1 | 0 |
| 3 | 88 | 140,293 | 0 | 0 | 0 | 0 | 40,293 | 1 | 1 | 0 |
| 4 | 41 | 100,000 | 0 | 0 | 8,770 | 1 | 0 | 0 | 1 | 0 |
| 5 | 42 | 100,000 | 0 | 0 | 8,770 | 1 | 0 | 0 | 1 | 0 |
| 6 | 75 | 131,457 | 0 | 0 | 0 | 0 | 31,457 | 1 | 1 | 0 |
| 7 | 89 | 149,078 | 0 | 0 | 0 | 0 | 49,078 | 1 | 1 | 0 |
| 8 | 88 | 147,819 | 0 | 0 | 0 | 0 | 47,819 | 1 | 1 | 0 |
| 9 | 35 | 100,000 | 0 | 0 | 8,770 | 1 | 0 | 0 | 1 | 0 |
| 10 | 42 | 100,000 | 0 | 0 | 8,770 | 1 | 0 | 0 | 1 | 0 |
| 11 | 9 | 64,777 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 12 | 79 | 128,966 | 0 | 0 | 0 | 0 | 28,966 | 1 | 1 | 0 |
| 13 | 69 | 123,905 | 0 | 0 | 0 | 0 | 23,905 | 1 | 1 | 0 |
| 14 | 23 | 88,327 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 15 | 50 | 100,000 | 0 | 0 | 8,770 | 1 | 0 | 0 | 1 | 0 |
| 16 | 10 | 62,350 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 17 | 55 | 100,000 | 0 | 0 | 8,770 | 1 | 0 | 0 | 1 | 0 |
| 18 | 13 | 72,769 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 19 | 11 | 63,608 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 20 | 27 | 85,524 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 21 | 63 | 108,827 | 0 | 0 | 0 | 0 | 8,827 | 1 | 1 | 0 |
| 22 | 67 | 121,387 | 0 | 0 | 0 | 0 | 21,387 | 1 | 1 | 0 |
| 23 | 71 | 126,422 | 0 | 0 | 0 | 0 | 26,422 | 1 | 1 | 0 |
| 24 | 10 | 69,916 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 25 | 77 | 126,448 | 0 | 0 | 0 | 0 | 26,448 | 1 | 1 | 0 |
| 26 | 45 | 100,000 | 0 | 0 | 8,770 | 1 | 0 | 0 | 1 | 0 |
| 27 | 91 | 151,595 | 0 | 0 | 0 | 0 | 51,595 | 1 | 1 | 0 |
| 28 | 87 | 146,560 | 0 | 0 | 0 | 0 | 46,560 | 1 | 1 | 0 |
| 29 | 65 | 118,870 | 0 | 0 | 0 | 0 | 18,870 | 1 | 1 | 0 |
| 30 | 25 | 91,100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 31 | 87 | 139,035 | 0 | 0 | 0 | 0 | 39,035 | 1 | 1 | 0 |
| 32 | 74 | 130,198 | 0 | 0 | 0 | 0 | 30,198 | 1 | 1 | 0 |
| 33 | 26 | 92,358 | 1,128 | 1 | 0 | 0 | 0 | 0 | 1 | 0 |
| 34 | 14 | 67,384 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 35 | 84 | 135,259 | 0 | 0 | 0 | 0 | 35,259 | 1 | 1 | 0 |
| 36 | 27 | 93,617 | 2,387 | 1 | 0 | 0 | 0 | 0 | 1 | 0 |
| 37 | 15 | 68,643 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 38 | 38 | 99,937 | 8,707 | 1 | 0 | 0 | 0 | 0 | 1 | 0 |
| 39 | 100 | 155,397 | 0 | 0 | 0 | 0 | 55,397 | 1 | 1 | 0 |
| 40 | 38 | 100,000 | 0 | 0 | 8,770 | 1 | 0 | 0 | 1 | 0 |

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| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 41 | 20 | 84,006 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 42 | 45 | 100,000 | 0 | 0 | 8,770 | 1 | 0 | 0 | 1 | 0 |
| 43 | 8 | 59,833 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 44 | 50 | 100,000 | 0 | 0 | 8,770 | 1 | 0 | 0 | 1 | 0 |
| 45 | 2 | 52,281 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 46 | 6 | 57,315 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 47 | 80 | 130,224 | 0 | 0 | 0 | 0 | 30,224 | 1 | 1 | 0 |
| 48 | 97 | 159,147 | 0 | 0 | 0 | 0 | 59,147 | 1 | 1 | 0 |
| 49 | 22 | 86,910 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 50 | 29 | 88,356 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 51 | 44 | 100,000 | 0 | 0 | 8,770 | 1 | 0 | 0 | 1 | 0 |
| 52 | 65 | 111,345 | 0 | 0 | 0 | 0 | 11,345 | 1 | 1 | 0 |
| 53 | 60 | 112,577 | 0 | 0 | 0 | 0 | 12,577 | 1 | 1 | 0 |
| 54 | 9 | 68,617 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 55 | 14 | 67,384 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 56 | 48 | 100,000 | 0 | 0 | 8,770 | 1 | 0 | 0 | 1 | 0 |
| 57 | 68 | 115,121 | 0 | 0 | 0 | 0 | 15,121 | 1 | 1 | 0 |
| 58 | 6 | 64,841 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 59 | 30 | 89,773 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 60 | 72 | 120,155 | 0 | 0 | 0 | 0 | 20,155 | 1 | 1 | 0 |
| 61 | 77 | 133,974 | 0 | 0 | 0 | 0 | 33,974 | 1 | 1 | 0 |
| 62 | 78 | 135,232 | 0 | 0 | 0 | 0 | 35,232 | 1 | 1 | 0 |
| 63 | 15 | 76,997 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 64 | 71 | 118,897 | 0 | 0 | 0 | 0 | 18,897 | 1 | 1 | 0 |
| 65 | 49 | 100,000 | 0 | 0 | 8,770 | 1 | 0 | 0 | 1 | 0 |
| 66 | 44 | 100,000 | 0 | 0 | 8,770 | 1 | 0 | 0 | 1 | 0 |
| 67 | 25 | 91,100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 68 | 55 | 100,000 | 0 | 0 | 8,770 | 1 | 0 | 0 | 1 | 0 |
| 69 | 13 | 72,769 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 70 | 23 | 79,859 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 71 | 57 | 101,276 | 0 | 0 | 0 | 0 | 1,276 | 1 | 1 | 0 |
| 72 | 66 | 120,129 | 0 | 0 | 0 | 0 | 20,129 | 1 | 1 | 0 |
| 73 | 63 | 116,353 | 0 | 0 | 0 | 0 | 16,353 | 1 | 1 | 0 |
| 74 | 43 | 100,000 | 0 | 0 | 8,770 | 1 | 0 | 0 | 1 | 0 |
| 75 | 56 | 107,542 | 0 | 0 | 0 | 0 | 7,542 | 1 | 1 | 0 |
| 76 | 87 | 146,560 | 0 | 0 | 0 | 0 | 46,560 | 1 | 1 | 0 |
| 77 | 88 | 147,819 | 0 | 0 | 0 | 0 | 47,819 | 1 | 1 | 0 |
| 78 | 46 | 100,000 | 0 | 0 | 8,770 | 1 | 0 | 0 | 1 | 0 |
| 79 | 56 | 107,542 | 0 | 0 | 0 | 0 | 7,542 | 1 | 1 | 0 |
| 80 | 14 | 75,581 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 81 | 67 | 113,862 | 0 | 0 | 0 | 0 | 13,862 | 1 | 1 | 0 |
| 82 | 27 | 93,617 | 2,387 | 1 | 0 | 0 | 0 | 0 | 1 | 0 |
| 83 | 97 | 151,621 | 0 | 0 | 0 | 0 | 51,621 | 1 | 1 | 0 |
| 84 | 23 | 88,327 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 85 | 66 | 112,603 | 0 | 0 | 0 | 0 | 12,603 | 1 | 1 | 0 |
| 86 | 33 | 100,000 | 0 | 0 | 8,770 | 1 | 0 | 0 | 1 | 0 |
| 87 | 35 | 97,330 | 6,100 | 1 | 0 | 0 | 0 | 0 | 1 | 0 |
| 88 | 14 | 67,384 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 89 | 9 | 61,091 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

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| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 90 | 39 | 100,000 | 0 | 0 | 8,770 | 1 | 0 | 0 | 1 | 0 |
| 91 | 95 | 149,104 | 0 | 0 | 0 | 0 | 49,104 | 1 | 1 | 0 |
| 92 | 18 | 81,245 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 93 | 26 | 84,108 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 94 | 20 | 75,611 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 95 | 8 | 59,833 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 96 | 48 | 100,000 | 0 | 0 | 8,770 | 1 | 0 | 0 | 1 | 0 |
| 97 | 96 | 150,363 | 0 | 0 | 0 | 0 | 50,363 | 1 | 1 | 0 |
| 98 | 38 | 100,000 | 0 | 0 | 8,770 | 1 | 0 | 0 | 1 | 0 |
| 99 | 22 | 86,839 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 100 | 2 | 52,281 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| For a population cohort of | 100,000 | individuals | 26,872 | 6 | 184,170 | 21 | 1,149,246 | 39 | | 34 |
| For total population of | 150,000 | individuals | 40,308 | | 276,255 | | 1,723,869 | | | 100 |

**Report 3.45f: Glut analysis**

| Yield variation | Net energy at end of year after taking into account gains and | Population per 100,000 that could be supported in the current | Surplus or unfed manpower | Years where harvest + 20% reduction in rations + strategy to maintain 15% buffer in granaries failed to feed all the population | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Yrs m/p gt 100,000 | Run of two years | Run of three years | Run of four years | 0 4,999 | 5,000 9,999 | 10,000 14,999 | 15,000 19,999 | 20,000 24,999 | 25,000 29,999 | 30,000 34,999 | 35,000 39,999 | 40,000 100,000 |
| 55 | 112,563 | 106,284 | 6,284 | 1 | | | | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 30 | 103,147 | 97,393 | -2,607 | 0 | 0 | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 88 | 148,582 | 140,293 | 40,293 | 1 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 41 | 105,908 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 42 | 105,908 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 75 | 139,223 | 131,457 | 31,457 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 89 | 157,885 | 149,078 | 49,078 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 88 | 156,552 | 147,819 | 47,819 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 35 | 105,908 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 42 | 105,908 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 71,088 | 64,777 | -35,223 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 79 | 136,585 | 128,966 | 28,966 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 69 | 131,225 | 123,905 | 23,905 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| 23 | 93,816 | 88,327 | -11,673 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 50 | 105,908 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 68,517 | 62,350 | -37,650 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 55 | 105,908 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 13 | 79,171 | 72,769 | -27,231 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | 69,850 | 63,608 | -36,392 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 27 | 91,178 | 85,524 | -14,476 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 63 | 115,257 | 108,827 | 8,827 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 67 | 128,559 | 121,387 | 21,387 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| 71 | 133,891 | 126,422 | 26,422 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 10 | 76,487 | 69,916 | -30,084 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 77 | 133,919 | 126,448 | 26,448 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 45 | 105,908 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 91 | 160,551 | 151,595 | 51,595 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 87 | 155,219 | 146,560 | 46,560 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 65 | 125,893 | 118,870 | 18,870 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 25 | 96,482 | 91,100 | -8,900 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 87 | 147,249 | 139,035 | 39,035 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 74 | 137,890 | 130,198 | 30,198 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 26 | 97,815 | 92,358 | -7,642 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 14 | 73,849 | 67,384 | -32,616 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 84 | 143,250 | 135,259 | 35,259 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 27 | 99,148 | 93,617 | -6,383 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 15 | 75,182 | 68,643 | -31,357 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 38 | 105,841 | 99,937 | -63 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 100 | 164,578 | 155,397 | 55,397 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 38 | 105,908 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | 89,750 | 84,006 | -15,994 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 45 | 105,908 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

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| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8 | 65,851 | 59,833 | -40,167 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 50 | 105,908 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 57,853 | 52,281 | -47,719 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 63,185 | 57,315 | -42,685 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 80 | 137,918 | 130,224 | 30,224 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 97 | 168,549 | 159,147 | 59,147 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 22 | 92,483 | 86,910 | -13,090 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 29 | 93,844 | 88,356 | -11,644 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 44 | 105,908 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 65 | 117,923 | 111,345 | 11,345 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 60 | 119,228 | 112,577 | 12,577 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 75,154 | 68,617 | -31,383 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 14 | 73,849 | 67,384 | -32,616 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 48 | 105,908 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 68 | 121,922 | 115,121 | 15,121 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 6 | 71,155 | 64,841 | -35,159 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 30 | 95,177 | 89,773 | -10,227 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 72 | 127,254 | 120,155 | 20,155 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| 77 | 141,889 | 133,974 | 33,974 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 78 | 143,222 | 135,232 | 35,232 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 15 | 83,152 | 76,997 | -23,003 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 71 | 125,921 | 118,897 | 18,897 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 49 | 105,908 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 44 | 105,908 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 25 | 96,482 | 91,100 | -8,900 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 55 | 105,908 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 13 | 79,171 | 72,769 | -27,231 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 23 | 85,846 | 79,859 | -20,141 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 57 | 107,259 | 101,276 | 1,276 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 66 | 127,226 | 120,129 | 20,129 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| 63 | 123,227 | 116,353 | 16,353 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 43 | 105,908 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 56 | 113,896 | 107,542 | 7,542 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 87 | 155,219 | 146,560 | 46,560 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 88 | 156,552 | 147,819 | 47,819 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 46 | 105,908 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 56 | 113,896 | 107,542 | 7,542 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 14 | 81,819 | 75,581 | -24,419 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 67 | 120,589 | 113,862 | 13,862 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 27 | 99,148 | 93,617 | -6,383 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 97 | 160,579 | 151,621 | 51,621 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 23 | 93,816 | 88,327 | -11,673 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 66 | 119,256 | 112,603 | 12,603 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 33 | 105,908 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 35 | 103,080 | 97,330 | -2,670 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 14 | 73,849 | 67,384 | -32,616 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 67,184 | 61,091 | -38,909 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 39 | 105,908 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 95 | 157,913 | 149,104 | 49,104 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

Continued on next page

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 18 | 87,151 | 81,245 | -18,755 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 26 | 89,845 | 84,108 | -15,892 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | 81,847 | 75,611 | -24,389 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 65,851 | 59,833 | -40,167 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 48 | 105,908 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 96 | 159,246 | 150,363 | 50,363 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 38 | 105,908 | 100,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 22 | 92,416 | 86,839 | -13,161 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 57,853 | 52,281 | -47,719 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4,619 | 10,890,005 | 10,230,238 | | 39 | 16 | 6 | 0 | 1 | 4 | 4 | 4 | 4 | 3 | 4 | 3 | 12 |

# CLOTHCALC

# Module 1. Area of cloth to make garments

**Report 4.1a: Dimensions and unit areas of cloth required to make Egyptian garments plus associated references. All dimensions in metres and areas in square metres.**

### BAG-TUNICS

| Reference for full length bag-tunics Vogelsang-Eastwood 1993: 139, Table 2 | | | | | | | | | | | | | | Average | Area |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Length | 1.28 | 1.2 | 1.135 | 1.37 | 1.38 | 1.35 | 1.21 | 1.28 | 1.27 | 1.24 | 1.18 | 1.18 | 1.4 | 1.26 | **2.55** |
| Width | 0.88 | 0.7 | 0.95 | 0.85 | 1.03 | 0.88 | 1.09 | 1.01 | 1.25 | 1.255 | 1.17 | 1.1 | 1.15 | 1.01 | |

| Ref. for short bag-tunics Vogelsang-Eastwood 1993: 151 | | | | | Average | Area |
|---|---|---|---|---|---|---|
| Length | 0.7 | 0.92 | 0.91 | 0.93 | 0.87 | **1.48** |
| Width | 0.88 | 0.7 | 0.95 | 0.85 | 0.85 | |

### KILTS

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Ref. for workmans short kilt Vogelsang-Eastwood 1993: 181. | length = | 1.2 | width = | 0.6 | area = | **0.72** | Average |
| Ref Digital Eg't. Deshasheh kilt (3rd IP ca. 800 BC?) UC 31173 | length = | 1.03 | width = | 0.75 | area = | **0.77** | **0.75** |
| Ref. for official short kilt Vogelsang-Eastwood 1992: 14. | length = | 1.2 | width = | 0.6 | area = | **0.72** | Average |
| Ref. for official short kilt Schiaparelli 1927: 92. | length = | 1.6 | width = | 0.56 | area = | **0.9** | **0.81** |
| Ref. for official long kilt Vogelsang-Eastwood 1993: 181. | length = | 3 | width = | 1 | area = | **3** | |
| Ref. for sash kilt (kilt only) Metropoltitan Museum acc. no. 36.3.176 | length = | 1.88 | width = | 0.55 | area = | **1.03** | Average |
| Ref. for sash kilt (kilt only) Vogelsang-Eastwood 1993: 181. | length = | 2.5 | width = | 0.6 | area = | **1.5** | **1.27** |

### LOIN CLOTHS

| | length | width | Area | | Area max |
|---|---|---|---|---|---|
| Loin cloths estimated from Amarna samples Ref Kemp and Vogesang-Eastwood 2001: 186, Figure 6.17. Assume loin cloth can be made from two triangles made from a square of cloth and sown together | 1 | 0.45 | 0.45 | | **0.45** |

### APRONS

| | | | | | Area |
|---|---|---|---|---|---|
| Ref. for apron Vogelsang-Eastwood 1992: 12-13 | Semi-circle lower part | | | | |
| | length = | 0.52 | width = | 0.45 | **0.23** |
| | Waistband | | | | |
| | length = | 0.36 | width = | 0.12 | **0.04** |
| | First tie | | | | |
| | length = | 0.9 | width = | 0.08 | **0.07** |
| | Second tie | | | | |
| | length = | 0.9 | width = | 0.08 | **0.07** |
| | Total area of apron | | | | **0.41** |

### SASHES

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Typical simple sash Vogelsang-Eastwood 1992: 21. | length = | 3 | width = | 0.15 | area = | **0.45** | Av. |
| Ref for sashes Vogelsang-Eastwood 1993: 73-76. | length = | 1.07 | width = | 0.2 | area = | **0.21** | **0.39** |
| | length = | 3 | width = | 0.165 | area = | **0.5** | |
| Ref for large sash Janssen 1975: 286. | length = | 1.8 | width = | 0.375 | area = | **0.68** | |

### KERCHIEFS

| | | | | | | | Av. |
|---|---|---|---|---|---|---|---|
| Ref. for kerchiefs Winlock 1941: 10. | length = | 0.48 | width = | 0.63 | area = | **0.3** | **0.32** |
| Ref. for kerchiefs Vogelsang-Eastwood 1992: 46 | length = | 0.65 | width = | 0.5 | area = | **0.33** | |
| Workers kerchiefs Vogelsang-Eastwood 1992: 45 | length = | 0.95 | width = | 0.95 | area = | **0.9** | |

### DRESSES

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Ref. V necked dress sleeves Vogelsang-Eastwood 1992: 30-31. | length = | 1.36 | width = | 0.8 | area = | **1.09** | Combined |
| Ref. V necked dress wrap-around skirt alone Vogelsang-Eastwood 1992: 30-31. | length = | 1.2 | width = | 1 | area = | **1.2** | **2.29** |
| Ref. for long wrap-around dress Vogelsang-Eastwood 1993: 101. | length = | 3.05 | width = | 1.075 | area = | **3.28** | |
| Ref. for complex wrap-around dress Vogelsang-Eastwood 1993: 181. | length = | 4 | width = | 1 | area = | **4** | Average |
| Ref. for complex wrap-around dress Bruyère 1937: II, Figure 30. | length = | 1.68 | width = | 1.37 | area = | **2.3** | **3.15** |

### SHAWLS

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Ref. for short shawl Vogelsang-Eastwood 1992: 37. | length = | 0.75 | width = | 0.75 | area = | **0.56** | |
| Ref. for medium shawl Brunton 1940: 522, 527. | length = | 1.4 | width = | 0.9 | area = | **1.26** | Average |
| Ref. for med. shawl Vogelsang-Eastwood 1993: 101,181. | length = | 1.28 | width = | 1.2 | area = | **1.54** | **1.79** |
| Ref. for Kha's long shawls Schiaparelli 1927: 93. | length = | 4.3 | width = | 0.6 | area = | **2.58** | |

### SKIRTS

| | | | | | | |
|---|---|---|---|---|---|---|
| Ref. for woman's long skirt Vogelsang-Eastwood 1992: 15. | length = | 1.3 | width = | 0.6 | area = | **0.78** |
| Ref. for woman's long skirt Vogelsang-Eastwood 1993: 181. | length = | 3 | width = | 0.8 | area = | **2.4** |

### CLOAKS

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Simple wrap-around cloak Vogelsang-Eastwood 1992: 40. | length = | 1.4 | width = | 1.2 | area = | **1.68** | Av. |
| Knotted wrap-around cloak Vogelsang-Eastwood 1992: 40. | length = | 1.4 | width = | 2 | area = | **2.8** | **2.24** |
| Complex long wrap-around cloak Vogelsang-Eastwood 1993: 181. | length = | 3 | width = | 1.2 | area = | **3.6** | |
| Complex long wrap-around cloak Vogelsang-Eastwood 1992: 42. | length = | 2.1 | width = | 1.15 | area = | **2.42** | Av. |
| Typical long wrap-around cloak Vogelsang-Eastwood 1992: 40. | length = | 3 | width = | 1.2 | area = | **3.6** | **3.21** |

**Report 4.1b: Unit area of cloth to make garment**

Male | Female | Both sexes

| Size of elite social economic groups 1-3 | 2,970 |
|---|---|
| Size of social economic groups 4-5 | 97,030 |

| Socio-economic group | No. | Gender | Pop. | Loin cloths | Kilts Long | Kilts Short | Kilts Sash | Δ apron | Long bag-tunic | Sashes | Short bag-tunic | Shawls Med/long | Shawls Short | Wrap-ar. cloaks Simple | Wrap-ar. cloaks Complex | Female skirt Long | Female skirt Short | V neck dress | Wrap-ar. Dress Long | Wrap-ar. Dress Complex | Ker-chiefs | Blankets see Report 4.1i6 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Royaly, nobles and high elite | 138 | Male 10+ | 46 | 0.45 | 3 | 0.81 | 1.27 | 0.41 | 2.55 | 0.39 | 1.48 | 1.79 | 1.79 | 2.24 | 3.21 | | | | | | 0.32 | 2.1 | 21.81 |
| | | Female 10+ | 46 | 0.41 | | | | | | 0.36 | | 1.65 | 1.65 | 1.55 | 2.23 | 2.4 | 0.78 | 2.29 | 3.28 | 3.15 | 0.29 | 2 | 22.04 |
| | | Child 4-9 | 23 | 0.32 | | 0.567 | 1 | 0.287 | 1.79 | 0.27 | 1.04 | 1.25 | 1.25 | 1.176 | 1.69 | | | 1.603 | 2.3 | 1.61 | 0.224 | 1.2 | 17.577 |
| | | Child 0-3 | 23 | 0.252 | | | | | | | | | 1 | | | | | | | | | 1 | 2.252 |
| 2. Senior officials | 303 | Male 10+ | 100 | 0.45 | 3 | 0.81 | 1.27 | 0.41 | 2.55 | 0.39 | 1.48 | 1.79 | 1.79 | 1.68 | 3.21 | | | | | | 0.32 | 2.1 | 21.25 |
| | | Female 10+ | 100 | 0.41 | | | | | | 0.36 | | 1.65 | 1.65 | 1.55 | 2.23 | 2.4 | 0.78 | 2.29 | 3.28 | 3.15 | 0.29 | 2 | 22.04 |
| | | Child 4-9 | 51 | 0.32 | | 0.567 | | 0.287 | 1.79 | 0.27 | 1.04 | 1.25 | 1.25 | 1.176 | | | | 1.603 | 2.3 | 1.61 | 0.224 | 1.2 | 14.887 |
| | | Child 0-3 | 51 | 0.252 | | | | | | | | | 1 | | | | | | | | | 1 | 2.252 |
| 3. Professionals, priests, army officers, scribes and mayors | 2,530 | Male 10+ | 840 | 0.45 | 3 | 0.81 | 1.27 | 0.41 | 2.55 | 0.39 | 1.48 | 1.79 | 1.79 | 1.68 | 3.21 | | | | | | 0.32 | 2.1 | 21.25 |
| | | Female 10+ | 840 | 0.41 | | | | | | 0.36 | | 1.65 | 1.65 | 1.55 | 2.23 | 2.4 | 0.78 | 2.29 | 3.28 | 3.15 | 0.29 | 2 | 22.04 |
| | | Child 4-9 | 427 | 0.32 | | | | 0.287 | 1.79 | 0.27 | 1.04 | 1.25 | 1.25 | 1.176 | | | | 1.603 | 2.3 | 1.61 | 0.224 | 1.2 | 14.32 |
| | | Child 0-3 | 423 | 0.252 | | | | | | | | | 1 | | | | | | | | | 1 | 2.252 |
| 4. Lower professionals, skilled craftsmen small land owners | 10,000 | Male 10+ | 3,321 | 0.45 | 3 | 0.75 | 1.27 | 0.41 | 2.55 | 0.39 | 1.48 | 1.79 | 1.79 | 1.68 | 3.21 | | | | | | 0.9 | 2.1 | 21.77 |
| | | Female 10+ | 3,321 | 0.41 | | | | | | 0.36 | | 1.65 | 1.65 | 1.55 | | 2.4 | 0.78 | 2.29 | 3.28 | 3.15 | 0.83 | 2 | 20.35 |
| | | Child 4-9 | 1,689 | 0.32 | | | | | | | | 1.25 | 1.25 | 1.176 | | | | | 2.3 | | | 1.2 | 7.496 |
| | | Child 0-3 | 1,670 | 0.252 | | | | | | | | | 1 | | | | | | | | | 1 | 2.252 |
| 5. Farm workers + manual craft labourers | 87,030 | Male 10+ | 28,899 | 0.45 | | 0.75 | | | 2.55 | 0.39 | 1.48 | 1.79 | 1.79 | 1.68 | | | | | | | 0.9 | 2.1 | 13.88 |
| | | Female 10+ | 28,899 | 0.41 | | | | | | 0.36 | | 1.65 | 1.65 | 1.55 | | 2.4 | 0.78 | | 3.28 | | 0.83 | 2 | 14.91 |
| | | Child 4-9 | 14,699 | 0.32 | | | | | | | | | 1.25 | 1.176 | | | | | 2.3 | | | 1.2 | 6.246 |
| | | Child 0-3 | 14,534 | 0.252 | | | | | | | | | | | | | | | | | | 1 | 1.252 |
| | 100,000 | | 100,002 | 7.16 | 12 | 5.06 | 6.08 | 2.5 | 18.12 | 4.56 | 10.52 | 22.2 | 27.45 | 22.59 | 21.22 | 12 | 3.9 | 13.97 | 27.9 | 17.43 | 5.96 | 31.5 | 272.13 |

**Report 4.1c: Factors used for gender and maturity.**

| | | |
|---|---|---|
| **Gender factor** | Female | **0.92** |
| **Age Factor** | Child 0-3 | **0.56** |
| **Age Factor** | Child 4-9 | **0.7** |

| **UK Goverment Statistics 2004** | | |
|---|---|---|
| Av. height male | 1.753 | m |
| Av. height female | 1.614 | m |
| Av. height child 3 | 0.98 | m |
| Av. height child 7 | 1.22 | m |

**Report 4.1d: Cyprus V-NECK DRESS and WRAP-AROUND MANTLE DRESS**

| | | | | | | |
|---|---|---|---|---|---|---|
| Jones 2003: Plate LXXXVIII, v-neck dress | length = | 2.8 | Width = | 1.04 | Area = | **2.91** |
| Jones 2003: Plate LXXXIX, Tunic dress | length = | 2.57 | Width = | 1.07 | Area = | **2.75** |
| Jones 2003: Plate LXXXVIII, wrap-around mantle | length = | 1.96 | Width = | 2 | Area = | **3.92** |
| | | | | **Tunic + over-mantle** | Area = | **6.67** |

**Report 4.1e: ASSESSMENT OF AREA REQUIRED FOR A BELT AND BREECHCLOTH (KILT)**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Rehak 1996: 40, figure 2, waist-band belt | length = | 0.95 | Width = | 0.2 | Area = | 0.19 | Total area $m^2$ | **0.42** |
| Rehak 1996: 40, figure 2, breechcloth length | length = | 1.15 | Width = | 0.2 | Area = | 0.23 | | |

**Report 4.1f: AREA OF CLOTH REQUIRED TO MAKE CANAAN KILT AND SASH ca.3000 B.C.**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Sask | Length | 1.98 | Width | 0.17 | Area = | 0.34 | Total area $m^2$ | **1.57** |
| Kilt | Length | 1.4 | Width | 0.88 | Area = | 1.23 | | |

**Report 4.1g: Cyprus / NEAR EASTERN FLOUNCED SKIRT AND TOP SKIRT**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Jones 2005: 718 for main kilt | length = | 1.02 | width = | 1.32 | area = | 1.35 | Total area |
| Jones 2005: 718 for 2 x 4"frills | length = | 0.1 | width = | 1.47 | area = | 0.29 | |
| Jones 2005: 718 for 2 x 5"frills | length = | 0.13 | width = | 1.47 | area = | 0.38 | 2.02 |

**TOP** Ref Lillethun 2003: 472-475

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Back | length = | 0.41 | width = | 0.74 | area = | 0.3 | Total area |
| Front side left | length = | 0.19 | width = | 0.33 | area = | 0.06 | |
| Front side right | length = | 0.19 | width = | 0.33 | area = | 0.06 | 0.42 |

Skirt + top m2 = **2.44**

**Report 4.1h: Persentage breakdown of the populatin by socio-economic groups**

| Socio-economic groups | No. of families | Popul-ation |
|---|---|---|
| Socio-economic group 1 | 25 | 138 |
| Socio-economic group 2 | 55 | 303 |
| Socio-economic group 3 | 460 | 2,530 |
| Socio-economic group 4 | 1,820 | 10,000 |
| Socio-economic group 5 | 15,820 | 87,030 |
| | 18,180 | 100,000 |

| | Number |
|---|---|
| Socio-economic group 4+5 | 97,030 |
| Craftsmen socio-economic group 4 | 10,000 |
| **Socio-economic group 5** | **87,030** |

# Module 2. Literacy analysis to determine size of the élite

**Report 4.2a: Analysis of Egyptian population demographics.**

| Pop. demographics | | | |
|---|---|---|---|
| Children under 3 | 16.7 | | |
| Children under 4-9 | 16.89 | Males 10-50 | 45670 |
| Adolescents 10-15 | 12.07 | | |
| Adults 16-50 | 45.67 | | |
| Over 50 | 8.67 | | |
| **Total** | **100** | | |

| Socio-economic groups | % split by S E groups | Literate males | Elite popul-ation |
|---|---|---|---|
| Socio-economic group 1 | 5 | 25 | 138 |
| Socio-economic group 2 | 10 | 55 | 303 |
| Socio-economic group 3 | 85 | 460 | 2,530 |
| | 100 | 540 | 2,970 |

| | |
|---|---|
| Family size | 5.5 |
| Literate males | 540 |

**Report 4.2b: Analysis of Egyptian literacy levels.**

| Literacy levels/100,000 population | | | |
|---|---|---|---|
| Percentage of adults 15 or over | 54.34 | 54.34 | % |
| Adults 15 or over/100,000 population | 54,340 | 54,340 | |
| % literacy | 1 | 0.33 | % |
| Number of literate males and females = | 540 | 180 | |
| Percen. of males within total literate = | 100 | 100 | % |
| Number of literate males = | 540 | 180 | |
| Size nucleate family = | 5.5 | 5.5 | |
| Population of literate families | 2,970 | 990 | |

**Report 4.2c: Size of the nobles scioeconomic group.**

| Amarna population | | |
|---|---|---|
| Size of poulation = | 2.5 | million |
| Number of nobles tombs = | 19 | |
| No. of nobles tombs/100,000 of the pop. = | 1.3 | |
| Size nucleate family = | 5.5 | |
| Noble socio-economic group = | 7 | |

**Report 4.2d: No. of Noble families in Egypt**

| | | |
|---|---|---|
| Assume population of Egypt = | 2.5 | million |
| Assume size of noble family = | 10 | |
| % size of noble family used in table above | 0.01375 | |
| No. of noble families in Egypt = | 1 | |
| Scaling factor for Egypt = | 25 | |
| No. of workers in the cloth industry/100000 | 14,680 | |
| Rounded to nearest 10 = | 14,680 | |
| Total no of clothworkers in Egypt = | 367,000 | |

# Module 3. Number of garments required to clothe 100,000 people

**Report 4.3a: Number of articles owned/individual at any time.**

| Socio-economic group | No. | Gender | Pop. | Loin cloths | Kilts Long | Kilts Short | Kilts Sash | Δ apron | Long bag-tunic | Sashes | Short bag-tunic | Shawls Med/long | Shawls Short | Wrap-ar. cloaks Simple | Wrap-ar. cloaks Complex | Female skirt Long | Female skirt Short | V-neck dress | Wrap-ar. Dress Long | Wrap-ar. Dress Complex | Ker-chiefs | Blan-kets | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Royaly, nobles and high elite | 138 | Male 10+ | 46 | 35 | 15 | 6 | 5 | 12 | 10 | 10 | 7 | 8 | 12 | 8 | 6 | | | | | | 8 | 15 | 157 |
| | | Female 10+ | 46 | 15 | | | | | | 8 | | 4 | 5 | 3 | 3 | | | 8 | 8 | 4 | 3 | 6 | 67 |
| | | Child 4-9 | 23 | 5 | | 2 | | 4 | 2 | 2 | 4 | 1 | 1 | 1 | | | | 3 | 5 | | 2 | 4 | 36 |
| | | Child 0-3 | 23 | 2 | | | | | | | | | 2 | | | | | | | | | 2 | 6 |
| 2. Senior officials | 303 | Male 10+ | 100 | 8 | 5 | 3 | 2 | 6 | 6 | 4 | 4 | 4 | 5 | 4 | 2 | 0 | 0 | 0 | 0 | 0 | 6 | 8 | 67 |
| | | Female 10+ | 100 | 4 | 0 | 0 | 0 | 0 | 0 | 2 | | 2 | 3 | 2 | 1 | 0 | 0 | 4 | 4 | 2 | 2 | 5 | 31 |
| | | Child 4-9 | 51 | 2 | 0 | 0 | 0 | 3 | 0 | 1 | 3 | 2 | 3 | 1 | 0 | 0 | 0 | 1 | 3 | 0 | 2 | 2 | 23 |
| | | Child 0-3 | 51 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | | | 1 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 |
| 3. Professionals, priests, army officers, scribes and mayors | 2,530 | Male 10+ | 840 | 3 | 1 | 3 | 3 | 2 | 2 | 2 | 3 | 1 | 2 | 1 | 1 | | | | | | 2 | 5 | 31 |
| | | Female 10+ | 840 | 3 | | | | | | 1 | | 1 | 2 | 1 | 1 | | | 1 | 1 | 2 | 1 | 3 | 17 |
| | | Child 4-9 | 427 | 1 | | | | 1 | | | 1 | 1 | 1 | 1 | | | | 1 | 1 | | 1 | 1 | 10 |
| | | Child 0-3 | 423 | | | | | | | | | | | | | | | | | | | | 0 |
| 4. Lower professionals, skilled craftsmen small land owners | 10,000 | Male 10+ | 3,321 | 2 | 1 | 2 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | 1 | 2 | 16 |
| | | Female 10+ | 3,321 | 2 | | | | | | 1 | | 1 | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 13 |
| | | Child 4-9 | 1,689 | | | | | | | | | | | 1 | | | | | 1 | | 1 | 1 | 4 |
| | | Child 0-3 | 1,670 | | | | | | | | | | | | | | | | | | | | 0 |
| 5. Farm workers + manual craft labourers | 87,030 | Male 10+ | 28,899 | 1 | | 1 | | | 1 | 1 | 1 | | | 1 | | | | | | | 1 | 1 | 8 |
| | | Female 10+ | 28,899 | 1 | | | | | | 1 | | | | 1 | | | 1 | | | | 1 | 1 | 6 |
| | | Child 4-9 | 14,699 | | | | | | | | | | | | | | | | | | | | 0 |
| | | Child 0-3 | 14,534 | | | | | | | | | | | | | | | | | | | | 0 |
| **Total** | 100,000 | | 100,002 | 85 | 22 | 17 | 10 | 29 | 22 | 34 | 24 | 26 | 39 | 27 | 15 | 1 | 2 | 19 | 24 | 9 | 32 | 58 | 495 |

**Report 4.3b: Vogelsang-Eastwood's estimate of socio-economic group 3.**

**Assume width of cloth m** 1.1

| Male garment | Amount of cloth sq m | Unit area sq m | No. of garments | Female garment | Amount of cloth sq m | Unit area sq m | No. of garments |
|---|---|---|---|---|---|---|---|
| Loincloth | 1.1 | 0.45 | 3 | Loincloth | 1.1 | 0 | 3 |
| Short Kilt | 2.2 | 0.81 | 3 | wrap-around skirt | 3.3 | 2 | 2 |
| Long Kilt | 3.3 | 3 | 1 | Simple wrap-around dress | 3.3 | 3 | 1 |
| Sash-kilt | 3.3 | 1.27 | 3 | Complex wrap-around dress | 4.4 | 3 | 2 |
| Apron | 0.55 | 0.41 | 2 | Cloak | 3.3 | 2 | 2 |
| Long bag-tunic | 4.4 | 2.55 | 2 | Total | 15.4 | | 10 |
| Short bag-tunic | 3.3 | 1.48 | 3 | | | | |
| Cloak | 3.3 | 2.24 | 2 | | | | |
| Total | 21.45 | | 19 | | | | |

**Report 4.3c: Kha and Merit analysis comparing values of items in the tomb**

| | |
|---|---|
| Total Kha's goods | 3,919 |
| Kha's clothing | 1,395 |
| A. Kha's goods less clothing | 2,524 |
| Total Merit's goods | 787 |
| Merit's bedding and linen | 150 |
| B. Merit's goods less bedding/linen | 637 |
| Total A + B | 3,161 |
| Ratio Kha to Merit total goods | 5 |
| C. Sum of cloths, bedding and linen | 1,545 |

| | |
|---|---|
| Ratio Kha to Merit less clothes, bedding & linen | 4 |
| **Prorating C. proportional to A & B** | |
| D. Allocation to Kha | 1,234 |
| E. Allocation to Merit | 311 |
| Revised Kha's goods A+D | 3,758 |
| Revised Merit's goods B+E | 948 |
| Revised Kha/Merit ratio | 4 |
| Ratio of Kha to Merit | 2.1 |
| % Merit to Kha | 47.1 |

**Report 4.3d Area of cloth allocated to Kha and Merit**

| | | Loin cloths | Kilts Long | Kilts Short | Kilts Sash | Δ apron | Long bag-tunic | Sashes | Short bag-tunic | Shawls Med/long | Shawls Short | Wrap-ar. cloaks Simple | Wrap-ar. cloaks Complex | Female skirt Long | Female skirt Short | V-neck dress | Wrap-ar. Dress Long | Wrap-ar. Dress Complex | Ker-chiefs | Blan-kets | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. of garments | Kha | 0.45 | 3 | 0.81 | 1.27 | 0.41 | 2.55 | 0.39 | 1.48 | 1.79 | 1.79 | 2.24 | 3.21 | 0 | 0 | 0 | 0 | 0 | 0.32 | 2.1 | 21.81 |
| | | 0.41 | 0 | 0 | 0 | 0 | 0 | 0.36 | 0 | 1.65 | 1.65 | 1.55 | 2.23 | 2.4 | 0.78 | 2.29 | 3.28 | 3.15 | 0.29 | 2 | 22.04 |
| Unit area garments | Merit | 35 | 15 | 6 | 5 | 12 | 10 | 10 | 7 | 8 | 12 | 8 | 6 | 0 | 0 | 0 | 0 | 0 | 8 | 15 | 157 |
| | | 15 | 0 | 0 | 0 | 0 | 0 | 8 | 0 | 4 | 5 | 3 | 3 | 0 | 0 | 8 | 8 | 4 | 3 | 6 | 67 |
| Total area Kha | | 15.75 | 45 | 4.86 | 6.35 | 4.92 | 25.5 | 3.9 | 10.36 | 14.32 | 21.48 | 17.92 | 19.26 | 0 | 0 | 0 | 0 | 0 | 2.56 | 31.5 | 223.68 |
| Total area Merit | | 6.15 | 0 | 0 | 0 | 0 | 0 | 2.88 | 0 | 6.6 | 8.25 | 4.65 | 6.69 | 0 | 0 | 18.32 | 26.24 | 12.6 | 0.87 | 12 | 105.25 |

**Report 4.3e: Number of garments on averaged owned by each socio-economic group**

| Socio-economic groups | 1. High elite | 2. Senior officials | 3. Profes-sionals | 4. Crafts-men | 5. Farm workers | Total |
|---|---|---|---|---|---|---|
| **Male 10+** | 7,222 | 6,700 | 26,040 | 53,136 | 231,192 | 324,290 |
| **Female 10+** | 3,082 | 3,100 | 14,280 | 43,173 | 173,394 | 237,029 |
| **Child 0-9** | 966 | 1,326 | 4,270 | 6,756 | - | 13,318 |
| **Total** | 11,270 | 11,126 | 44,590 | 103,065 | 404,586 | **574,637** |

**Report 4.3f: Number of garments on averaged owned by each socio-economic group**

| Garment types | 1. High elite | 2. Senior officials | 3. Profes-sionals | 4. Crafts-men | 5. Farm workers | Total |
|---|---|---|---|---|---|---|
| Loin Cloths | 2,461 | 1,353 | 5,467 | 13,284 | 57,798 | 80,363 |
| Kilts | 1,242 | 1,000 | 5,880 | 9,963 | 28,899 | 46,984 |
| bag-tunics | 920 | 1,153 | 4,627 | 6,642 | 57,798 | 71,140 |
| Sashes | 874 | 651 | 2,520 | 6,642 | 57,798 | 68,485 |
| Aprons | 644 | 753 | 2,107 | 3,321 | - | 6,825 |
| Shawls | 1,426 | 1,706 | 5,894 | 13,284 | - | 22,310 |
| Cloaks | 943 | 951 | 3,787 | 11,652 | 57,798 | 75,131 |
| Skirts and dresses | 1,104 | 1,204 | 4,214 | 18,294 | 28,899 | 53,715 |
| Kerchiefs | 552 | 902 | 2,947 | 8,331 | 57,798 | 70,530 |
| Blankets | 1,104 | 1,453 | 7,147 | 11,652 | 57,798 | 79,154 |
| **Total** | **11,270** | **11,126** | **44,590** | **103,065** | **404,586** | **574,637** |
| | | | | | Rounded to nearest 1000 | 575,000 |

**Report 4.3d: Adjusting socio-economic groups 1-2 for assumption that they have accumulated half of all garments by the age 25.**

Adjustment for conspicuous consumptionat age 25 = 100 % Ratio = 1

| | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Royaly, nobles and high elite | 138 | Male 10+ | 46 | 35 | 15 | 6 | 5 | 12 | 10 | 10 | 7 | 8 | 12 | 8 | 6 | 0 | 0 | 0 | 0 | 0 | 8 | 15 | 157 |
| | | Female 10+ | 46 | 15 | 0 | 0 | 0 | 0 | 0 | 8 | 0 | 4 | 5 | 3 | 3 | 0 | 0 | 8 | 8 | 4 | 3 | 6 | 67 |
| | | Child 4-9 | 23 | 5 | 0 | 2 | 0 | 4 | 2 | 2 | 4 | 1 | 1 | 1 | 0 | 0 | 0 | 3 | 5 | 0 | 2 | 4 | 36 |
| | | Child 0-3 | 23 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 6 |
| 2. Senior officials | 303 | Male 10+ | 100 | 8 | 5 | 3 | 2 | 6 | 6 | 4 | 4 | 4 | 5 | 4 | 2 | 0 | 0 | 0 | 0 | 0 | 6 | 8 | 67 |
| | | Female 10+ | 100 | 4 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 2 | 3 | 2 | 1 | 0 | 0 | 4 | 4 | 2 | 2 | 5 | 31 |
| | | Child 4-9 | 51 | 2 | 0 | 0 | 0 | 3 | 0 | 1 | 3 | 2 | 3 | 1 | 0 | 0 | 0 | 1 | 3 | 0 | 2 | 2 | 23 |
| | | Child 0-3 | 51 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 |
| 3. Professionals, priests, army officers, scribes and mayors | 2,530 | Male 10+ | 840 | 3 | 1 | 3 | 3 | 2 | 2 | 2 | 3 | 1 | 2 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 2 | 5 | 31 |
| | | Female 10+ | 840 | 3 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 2 | 1 | 1 | 0 | 0 | 1 | 1 | 2 | 1 | 3 | 17 |
| | | Child 4-9 | 427 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 10 |
| | | Child 0-3 | 423 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4. Lower professionals, skilled craftsmen small land owners | 10,000 | Male 10+ | 3,321 | 2 | 1 | 2 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 16 |
| | | Female 10+ | 3,321 | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 13 |
| | | Child 4-9 | 1,689 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 4 |
| | | Child 0-3 | 1,670 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5. Farm workers + manual craft labourers | 87,030 | Male 10+ | 28,899 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 8 |
| | | Female 10+ | 28,899 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 6 |
| | | Child 4-9 | 14,699 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Child 0-3 | 14,534 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 100,000 | | 100,002 | 85 | 22 | 17 | 10 | 29 | 22 | 34 | 24 | 26 | 39 | 27 | 15 | 1 | 2 | 19 | 24 | 9 | 32 | 58 | 495 |

**Report 4.3e: Total cloth m² required to maintain wardrobe of Egyptian society across all socio-economic groups**

| Socio-economic group | No. | Gender | Pop. | Loin cloths | Kilts | | | Δ apron | Long bag-tunic | Sashes | Short bag-tunic | Shawls | | Wrap-around cloaks | | Female skirt | | V-neck dress | Wrap-around dress | | Ker-chiefs | Blan-kets | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Long | Short | Sash | | | | | Med/long | Short | Simple | Complex | Long | Short | | Long | Complex | | | |
| 1. Royaly, nobles and high elite | 138 | Male 10+ | 46 | 725 | 2070 | 224 | 292 | 226 | 1173 | 179 | 477 | 659 | 988 | 824 | 886 | 0 | 0 | 0 | 0 | 0 | 118 | 1449 | 10,290 |
| | | Female 10+ | 46 | 690 | 0 | 0 | 0 | 0 | 0 | 368 | 0 | 184 | 230 | 138 | 138 | 0 | 0 | 368 | 368 | 184 | 138 | 276 | 3,082 |
| | | Child 4-9 | 23 | 115 | 0 | 46 | 0 | 92 | 46 | 46 | 92 | 23 | 23 | 23 | 0 | 0 | 0 | 69 | 115 | 0 | 46 | 92 | 828 |
| | | Child 0-3 | 23 | 46 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 46 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 46 | 138 |
| 2. Senior officials | 303 | Male 10+ | 100 | 800 | 500 | 300 | 200 | 600 | 600 | 400 | 400 | 400 | 500 | 400 | 200 | 0 | 0 | 0 | 0 | 0 | 600 | 800 | 6,700 |
| | | Female 10+ | 100 | 400 | 0 | 0 | 0 | 0 | 0 | 200 | 0 | 200 | 300 | 200 | 100 | 0 | 0 | 400 | 400 | 200 | 200 | 500 | 3,100 |
| | | Child 4-9 | 51 | 102 | 0 | 0 | 0 | 153 | 0 | 51 | 153 | 102 | 153 | 51 | 0 | 0 | 0 | 51 | 153 | 0 | 102 | 102 | 1,173 |
| | | Child 0-3 | 51 | 51 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 51 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 51 | 153 |
| 3. Professionals, priests, army officers, scribes and mayors | 2,530 | Male 10+ | 840 | 2520 | 840 | 2520 | 2520 | 1680 | 1680 | 1680 | 2520 | 840 | 1680 | 840 | 840 | 0 | 0 | 0 | 0 | 0 | 1680 | 4200 | 26,040 |
| | | Female 10+ | 840 | 2520 | 0 | 0 | 0 | 0 | 0 | 840 | 0 | 840 | 1680 | 840 | 840 | 0 | 0 | 840 | 840 | 1680 | 840 | 2520 | 14,280 |
| | | Child 4-9 | 427 | 427 | 0 | 0 | 0 | 427 | 0 | 0 | 427 | 427 | 427 | 427 | 0 | 0 | 0 | 427 | 427 | 0 | 427 | 427 | 4,270 |
| | | Child 0-3 | 423 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4. Lower professionals, skilled craftsmen small land owners | 10,000 | Male 10+ | 3,321 | 6642 | 3321 | 6642 | 0 | 3321 | 3321 | 3321 | 3321 | 3321 | 3321 | 3321 | 3321 | 0 | 0 | 0 | 0 | 0 | 3321 | 6642 | 53,136 |
| | | Female 10+ | 3,321 | 6642 | 0 | 0 | 0 | 0 | 0 | 3321 | 0 | 3321 | 3321 | 3321 | 0 | 3321 | 3321 | 3321 | 3321 | 3321 | 3321 | 3321 | 43,173 |
| | | Child 4-9 | 1,689 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1689 | 0 | 0 | 0 | 0 | 1689 | 0 | 1689 | 1689 | 6,756 |
| | | Child 0-3 | 1,670 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5. Farm workers + manual craft labourers | 87,030 | Male 10+ | 28,899 | 28899 | 0 | 28899 | 0 | 0 | 28899 | 28899 | 28899 | 0 | 0 | 28899 | 0 | 0 | 0 | 0 | 0 | 0 | 28899 | 28899 | 231,192 |
| | | Female 10+ | 28,899 | 28899 | 0 | 0 | 0 | 0 | 0 | 28899 | 0 | 0 | 0 | 28899 | 0 | 0 | 28899 | 0 | 0 | 0 | 28899 | 28899 | 173,394 |
| | | Child 4-9 | 14,699 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Child 0-3 | 14,534 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 100,000 | | 100,002 | 79478 | 6731 | 38631 | 3012 | 6499 | 35719 | 68204 | 36289 | 10317 | 12720 | 69872 | 6325 | 3321 | 32220 | 5476 | 7313 | 5385 | 70280 | 79913 | 577,705 |

**Report 4.3f: Area of cloth m$^2$ to produce cloth required to make all the garments for 100,000 people in Egypt.**

| | Area of cloth m$^2$ required/100,000 population | | | | | |
|---|---|---|---|---|---|---|
| **Garment types** | **1. High elite** | **2. Senior officials** | **3. Profes-sionals** | **4. Crafts-men** | **5. Farm workers** | **Total** |
| Loin Cloths | 1,576 | 1,353 | 5,467 | 13,284 | 57,798 | 79,478 |
| Kilts | 2,632 | 1,000 | 5,880 | 9,963 | 28,899 | 48,374 |
| Bag-tunics | 1,788 | 1,153 | 4,627 | 6,642 | 57,798 | 72,008 |
| Sashes | 593 | 651 | 2,520 | 6,642 | 57,798 | 68,204 |
| Aprons | 318 | 753 | 2,107 | 3,321 | - | 6,499 |
| Shawls | 2,153 | 1,706 | 5,894 | 13,284 | - | 23,037 |
| Cloaks | 2,009 | 951 | 3,787 | 11,652 | 57,798 | 76,197 |
| Skirts and dresses | 1,104 | 1,204 | 4,214 | 18,294 | 28,899 | 53,715 |
| Kerchiefs | 302 | 902 | 2,947 | 8,331 | 57,798 | 70,280 |
| Blankets | 1,863 | 1,453 | 7,147 | 11,652 | 57,798 | 79,913 |
| **Total** | **14,338** | **11,126** | **44,590** | **103,065** | **404,586** | **577,705** |

Rounded to nearest 1000 **578,000**

**Report 4.3f: Area of cloth to produce cloth required to make all the garments for 100,000 people in NE Mediterranean.**

| | Area of cloth m$^2$ required/100,000 population | | | | | |
|---|---|---|---|---|---|---|
| **Garment types** | **1. High elite** | **2. Senior officials** | **3. Profes-sionals** | **4. Crafts-men** | **5. Farm workers** | **Total** |
| Loin Cloths | 1,576 | 1,353 | 5,467 | 13,284 | 57,798 | 79,478 |
| Kilts | 2,632 | 1,000 | 5,880 | 9,963 | 28,899 | 48,374 |
| Bag-tunics | 1,788 | 1,153 | 4,627 | 6,642 | 57,798 | 72,008 |
| Sashes | 593 | 651 | 2,520 | 6,642 | 57,798 | 68,204 |
| Aprons | 318 | 753 | 2,107 | 3,321 | - | 6,499 |
| Shawls | 2,153 | 1,706 | 5,894 | 13,284 | - | 23,037 |
| Cloaks | 2,411 | 1,141 | 4,544 | 13,982 | 69,358 | 91,436 |
| Skirts and dresses | 1,104 | 1,204 | 4,214 | 18,294 | 28,899 | 53,715 |
| Kerchiefs | 211 | 631 | 2,063 | 5,832 | 40,459 | 49,196 |
| Blankets | 2,236 | 1,744 | 8,576 | 13,982 | 69,358 | 95,896 |
| **Total** | **15,022** | **11,336** | **45,892** | **105,226** | **410,367** | **587,843** |

| | | | |
|---|---|---|---|
| % increase in demand for cloaks | 20 | Rounded to nearest 1000 | **588,000** |
| % increase in demand for blankets | 20 | | |
| % decrease in demand for kerchiefs | 30 | | |

# Module 4: Amortised wear and tear + accumulation

**Report 4.4a: Amortised anual area per individual taking into account wear and tear and accumulation.**

| Socio-economic group | No. | Gender | Pop. | Loin cloths | Kilts | | | Δ apron | Long bag-tunic | Sashes | Short bag-tunic | Shawls | | Wrap-around cloaks | | Female skirt | | V-neck dress | Wrap-around dress | | Ker-chiefs | Blan-kets | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Long | Short | Sash | | | | | Med/long | Short | Simple | Complex | Long | Short | | Long | Complex | | | |
| 1. Royaly, nobles and high elite | 138 | Male 10+ | 46 | 3.13 | 1.3 | 0.6 | 0.5 | 1 | 0.9 | 0.9 | 0.63 | 0.73 | 1 | 0.73 | 0.6 | 0 | 0 | 0 | 0 | 0 | 0.73 | 1.3 | 14.05 |
| | | Female 10+ | 46 | 1.3 | 0 | 0 | 0 | 0 | 0 | 0.73 | 0 | 0.4 | 0.5 | 0.33 | 0.33 | 0 | 0 | 0.73 | 0.73 | 0.4 | 0.33 | 0.6 | 6.38 |
| | | Child 4-9 | 23 | 0.5 | 0 | 0.27 | 0 | 0.4 | 0.27 | 0.27 | 0.4 | 0.167 | 0.167 | 0.167 | 0 | 0 | 0 | 0.33 | 0.5 | 0 | 0.27 | 0.4 | 4.111 |
| | | Child 0-3 | 23 | 0.27 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.27 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.27 | 0.81 |
| 2. Senior officials | 303 | Male 10+ | 100 | 0.73 | 0.5 | 0.33 | 0.27 | 0.6 | 0.6 | 0.4 | 0.4 | 0.4 | 0.5 | 0.4 | 0.27 | 0 | 0 | 0 | 0 | 0 | 0.6 | 0.73 | 6.73 |
| | | Female 10+ | 100 | 0.4 | 0 | 0 | 0 | 0 | 0 | 0.27 | 0 | 0.27 | 0.33 | 0.27 | 0.167 | 0 | 0 | 0.4 | 0.4 | 0.27 | 0.27 | 0.5 | 3.547 |
| | | Child 4-9 | 51 | 0.27 | 0 | 0 | 0 | 0.33 | 0 | 0.167 | 0.33 | 0.27 | 0.33 | 0.167 | 0 | 0 | 0 | 0.167 | 0.33 | 0 | 0.27 | 0.27 | 2.901 |
| | | Child 0-3 | 51 | 0.167 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.167 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.167 | 0.501 |
| 3. Professionals, priests, army officers, scribes and mayors | 2,530 | Male 10+ | 840 | 0.4 | 0.2 | 0.4 | 0.4 | 0.33 | 0.33 | 0.33 | 0.4 | 0.2 | 0.33 | 0.2 | 0.2 | 0 | 0 | 0 | 0 | 0 | 0.33 | 0.67 | 4.72 |
| | | Female 10+ | 840 | 0.4 | 0 | 0 | 0 | 0 | 0 | 0.2 | 0 | 0.2 | 0.33 | 0.2 | 0.2 | 0 | 0 | 0.2 | 0.2 | 0.33 | 0.2 | 0.4 | 2.86 |
| | | Child 4-9 | 427 | 0.2 | 0 | 0 | 0 | 0.2 | 0 | 0 | 0.2 | 0.2 | 0.2 | 0.2 | 0 | 0 | 0 | 0.2 | 0.2 | 0 | 0.2 | 0.2 | 2 |
| | | Child 0-3 | 423 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4. Lower professionals, skilled craftsmen small land owners | 10,000 | Male 10+ | 3,321 | 0.53 | 0.33 | 0.53 | 0 | 0.33 | 0.33 | 0.33 | 0.33 | 0.33 | 0.33 | 0.33 | 0.33 | 0 | 0 | 0 | 0 | 0 | 0.33 | 0.53 | 4.89 |
| | | Female 10+ | 3,321 | 0.53 | 0 | 0 | 0 | 0 | 0 | 0.33 | 0 | 0.33 | 0.33 | 0.33 | 0 | 0.33 | 0.33 | 0.33 | 0.33 | 0.33 | 0.33 | 0.33 | 4.16 |
| | | Child 4-9 | 1,689 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.33 | 0 | 0 | 0 | 0 | 0.33 | 0 | 0.33 | 0.33 | 1.32 |
| | | Child 0-3 | 1,670 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5. Farm workers + manual craft labourers | 87,030 | Male 10+ | 28,899 | 0.33 | 0 | 0.33 | 0 | 0 | 0.33 | 0.33 | 0.33 | 0 | 0 | 0.33 | 0 | 0 | 0 | 0 | 0 | 0 | 0.33 | 0.33 | 2.64 |
| | | Female 10+ | 28,899 | 0.33 | 0 | 0 | 0 | 0 | 0 | 0.33 | 0 | 0 | 0 | 0.33 | 0 | 0 | 0.33 | 0 | 0 | 0 | 0.33 | 0.33 | 1.98 |
| | | Child 4-9 | 14,699 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Child 0-3 | 14,534 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 100,000 | | 100,002 | 9.49 | 2.33 | 2.46 | 1.17 | 3.19 | 2.76 | 4.59 | 3.02 | 3.5 | 4.78 | 4.31 | 2.1 | 0.33 | 0.66 | 2.36 | 3.02 | 1.33 | 4.85 | 7.36 | 63.6 |

**Report 4.4b: Example for the area of cloth required for one loin cloth for the male population**

| Group | | | | | | |
|---|---|---|---|---|---|---|
| Socio-economic groups 1 | Unit area of cloth $m^2$ | 0.45 | No of garments required in 30 yrs | 94 | Total area of cloth required $m^2$/yr | 65 |
| | Amortised rate | 3.13 | Population of high elite adult males | 46 | | |
| Socio-economic groups 3 | Unit area of cloth $m^2$ | 0.45 | No of garments required in 30 yrs | 12 | Total area of cloth required $m^2$/yr | 151 |
| | Amortised rate | 0.4 | Population of professional males | 840 | | |
| Socio-economic groups 4 and 5 | Unit area of cloth $m^2$ | 0.45 | No of garments required in 30 yrs | 10 | Total area of cloth required $m^2$/yr | 4,292 |
| | Amortised rate | 0.33 | Population of male farm workers | 28,899 | | |

**Report 4.4c: Wear and tear amortised over 3.5, 5.5, and 7.5 years linked to worksheets W&T 3.5 yrs, W&T 5.5 yrs, and W&T 7.5 yrs.**

Wear and tear amortised over 3.5 years

Socio-economic groups 4-5

| | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 25 | 30 | 35 | 40 |
| 0.33 | 0.53 | 0.67 | 0.83 | 1 | 1.23 | 1.27 | 1.5 | 1.6 | 1.83 | 1.9 | 1.97 | 2.13 | 2.37 | 2.67 | 2.87 | 2.97 | 3.13 | 3.37 | 3.67 | 4.27 | 5.5 | 6.47 | 7.13 |

Wear and tear amortised over 5.5 years — Socio-economic groups 3

| | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** | **19** | **20** | **25** | **30** | **35** | 40 |
| **0.2** | **0.33** | **0.4** | **0.53** | **0.67** | **0.7** | **0.77** | **0.97** | **1.03** | **1.17** | **1.27** | **1.3** | **1.4** | **1.53** | **1.7** | **1.83** | **1.87** | **1.97** | **2.1** | **2.27** | **2.73** | **3.5** | **4.17** | 4.6 |

Wear and tear amortised over 7.5 years — Socio-economic groups 1-2

| | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 25 | 30 | 35 | 40 |
| 0.167 | 0.27 | 0.33 | 0.4 | 0.5 | 0.6 | 0.63 | 0.73 | 0.8 | 0.9 | 0.97 | 1 | 1.07 | 1.17 | 1.3 | 1.4 | 1.43 | 1.5 | 1.6 | 1.73 | 2.1 | 2.67 | 3.13 | 3.47 |

**5**

# Module 5: Total area of cloth required per year across all socio-economic groups

**Report 4.5a: Total amortised area of cloth required to be produced per annum.**

Male · Female · Both sexes

| Socio-economic group | No. | Gender | Pop. | Loin cloths | Kilts: Long | Kilts: Short | Kilts: Sash | Δ apron | Long bag-tunic | Sashes | Short bag-tunic | Shawls: Med/long | Shawls: Short | Wrap-around cloaks: Simple | Wrap-around cloaks: Complex | Female skirt: Long | Female skirt: Short | V-neck dress | Wrap-around dress: Long | Wrap-around dress: Complex | Ker-chiefs | Blan-kets | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Royaly, nobles and high elite | 138 | Male 10+ | 46 | 65 | 179 | 22 | 29 | 19 | 106 | 16 | 43 | 60 | 82 | 75 | 89 | 0 | 0 | 0 | 0 | 0 | 11 | 126 | 922 |
| | | Female 10+ | 46 | 25 | 0 | 0 | 0 | 0 | 0 | 12 | 0 | 30 | 38 | 24 | 34 | 0 | 0 | 77 | 110 | 58 | 4 | 55 | 467 |
| | | Child 4-9 | 23 | 4 | 0 | 4 | 0 | 3 | 11 | 2 | 10 | 5 | 5 | 5 | 0 | 0 | 0 | 12 | 26 | 0 | 1 | 11 | 99 |
| | | Child 0-3 | 23 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 14 |
| 2. Senior officials | 303 | Male 10+ | 100 | 33 | 150 | 27 | 34 | 25 | 153 | 16 | 59 | 72 | 90 | 67 | 87 | 0 | 0 | 0 | 0 | 0 | 19 | 153 | 985 |
| | | Female 10+ | 100 | 16 | 0 | 0 | 0 | 0 | 0 | 10 | 0 | 45 | 54 | 42 | 37 | 0 | 0 | 92 | 131 | 85 | 8 | 100 | 620 |
| | | Child 4-9 | 51 | 4 | 0 | 0 | 0 | 5 | 0 | 2 | 18 | 17 | 21 | 10 | 0 | 0 | 0 | 14 | 39 | 0 | 3 | 17 | 150 |
| | | Child 0-3 | 51 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 20 |
| 3. Professionals, priests, army officers, scribes and mayors | 2,530 | Male 10+ | 840 | 151 | 504 | 272 | 427 | 114 | 707 | 108 | 497 | 301 | 496 | 282 | 539 | 0 | 0 | 0 | 0 | 0 | 89 | 1,182 | 5,669 |
| | | Female 10+ | 840 | 138 | 0 | 0 | 0 | 0 | 0 | 60 | 0 | 277 | 457 | 260 | 375 | 0 | 0 | 385 | 551 | 873 | 49 | 672 | 4,097 |
| | | Child 4-9 | 427 | 27 | 0 | 0 | 0 | 25 | 0 | 0 | 89 | 107 | 107 | 100 | 0 | 0 | 0 | 137 | 196 | 0 | 19 | 102 | 909 |
| | | Child 0-3 | 423 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4. Lower professionals, skilled craftsmen small land owners | 10,000 | Male 10+ | 3,321 | 792 | 3,288 | 1,320 | 0 | 449 | 2,795 | 427 | 1,622 | 1,962 | 1,962 | 1,841 | 3,518 | 0 | 0 | 0 | 0 | 0 | 986 | 3,696 | 24,658 |
| | | Female 10+ | 3,321 | 722 | 0 | 0 | 0 | 0 | 0 | 395 | 0 | 1,808 | 1,808 | 1,699 | 0 | 2,630 | 855 | 2,510 | 3,595 | 3,452 | 910 | 2,192 | 22,576 |
| | | Child 4-9 | 1,689 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 655 | 0 | 0 | 0 | 0 | 1,282 | 0 | 0 | 669 | 2,606 |
| | | Child 0-3 | 1,670 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5. Farm workers + manual craft labourers | 87,030 | Male 10+ | 28,899 | 4,292 | 0 | 7,153 | 0 | 0 | 24,319 | 3,719 | 14,114 | 0 | 0 | 16,022 | 0 | 0 | 0 | 0 | 0 | 0 | 8,583 | 20,027 | 98,229 |
| | | Female 10+ | 28,899 | 3,910 | 0 | 0 | 0 | 0 | 0 | 3,433 | 0 | 0 | 0 | 14,782 | 0 | 0 | 7,459 | 0 | 0 | 0 | 7,915 | 19,073 | 56,552 |
| | | Child 4-9 | 14,699 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Child 0-3 | 14,534 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 100,000 | | 100,002 | 10,183 | 4,121 | 8,798 | 490 | 640 | 28,091 | 8,200 | 16,452 | 4,684 | 5,135 | 35,864 | 4,679 | 2,630 | 8,294 | 3,227 | 5,930 | 4,468 | 18,597 | 48,090 | 218,573 |
| | | | | | | | | | | | | | | | | | | | | | | Rounded to the nearest 100 = | 219,000 |

**Report 4.5b: Area of cloth collated by socio-economic group**

| Socio-economic groupings | Egypt: Area of cloth m² | Cyprus: Area of cloth m² |
|---|---|---|
| Socio-economic group 1 | 1,502 | 1,582 |
| Socio-economic group 2 | 1,775 | 1,871 |
| Socio-economic group 3 | 10,675 | 11,330 |
| Socio-economic group 4 | 49,840 | 52,125 |
| Socio-economic group 5 | 154,781 | 163,813 |
| **Total** | **218,573** | **230,721** |

**Report 4.5c: Annual area of cloth to produce cloth required to make all the garments for 100,000 people in Egypt.**

| Garment types | 1. High elite | 2. Senior officials | 3. Profes-sionals | 4. Crafts-men | 5. Farm workers | Total |
|---|---|---|---|---|---|---|
| Loin Cloths | 96 | 55 | 316 | 1,514 | 8,202 | 10,183 |
| Kilts | 234 | 211 | 1,203 | 4,608 | 7,153 | 13,409 |
| Bag-tunics | 170 | 230 | 1,293 | 4,417 | 38,433 | 44,543 |
| Sashes | 30 | 28 | 168 | 822 | 7,152 | 8,200 |
| Aprons | 22 | 30 | 139 | 449 | - | 640 |
| Shawls | 226 | 308 | 1,745 | 7,540 | - | 9,819 |
| Cloaks | 227 | 243 | 1,556 | 7,713 | 30,804 | 40,543 |
| Skirts and dresses | 283 | 361 | 2,142 | 14,324 | 7,439 | 24,549 |
| Kerchiefs | 16 | 30 | 157 | 1,896 | 16,498 | 18,597 |
| Blankets | 198 | 279 | 1,956 | 6,557 | 39,100 | 48,090 |
| **Total** | **1,502** | **1,775** | **10,675** | **49,840** | **154,781** | **218,573** |
| | | | Rounded to nearest 100 | | | **218,600** |

**Report 4.5d: Annual area of cloth to produce cloth required to make all the garments for 100,000 people in NE Mediterranean.**

| Garment types | 1. High elite | 2. Senior officials | 3. Profes-sionals | 4. Crafts-men | 5. Farm workers | Total |
|---|---|---|---|---|---|---|
| Loin Cloths | 96 | 55 | 316 | 1,514 | 8,202 | 10,183 |
| Kilts | 234 | 211 | 1,203 | 4,608 | 7,153 | 13,409 |
| Bag-tunics | 170 | 230 | 1,293 | 4,417 | 38,433 | 44,543 |
| Sashes | 30 | 28 | 168 | 822 | 7,152 | 8,200 |
| Aprons | 22 | 30 | 139 | 449 | - | 640 |
| Shawls | 226 | 308 | 1,745 | 7,540 | - | 9,819 |
| Cloaks | 272 | 292 | 1,867 | 9,256 | 36,965 | 48,652 |
| Skirts and dresses | 283 | 361 | 2,142 | 14,324 | 7,439 | 24,549 |
| Kerchiefs | 11 | 21 | 110 | 1,327 | 11,549 | 13,018 |
| Blankets | 238 | 335 | 2,347 | 7,868 | 46,920 | 57,708 |
| **Total** | **1,582** | **1,871** | **11,330** | **52,125** | **163,813** | **230,721** |
| % increase in demand for cloaks | 20 | | Rounded to nearest 100 | | | **230,800** |
| % increase in demand for blankets | 20 | | | | | |
| % decrease in demand for kerchiefs | 30 | | | | | |

# Module 6. Length of yarn required to satisfy demand

**Report 4.6a: Warp analysis Amarna data n= 3,144**

| | Warp Counts |
|---|---|
| 1 No of warps within range 0-10 | 1269 |
| 2 No of warps within range 11-15 | 1076 |
| 3 No of warps within range 16-20 | 653 |
| 4 No of warps within range 21-25 | 133 |
| 5 No of warps within range 26-30 | 13 |
| **Total** | **3,144** |
| | **% Warps** |
| 1 warps within range 0-10 | 40.4 |
| 2 warps within range 11-15 | 34.2 |
| 3 warps within range 16-20 | 20.8 |
| 4 warps within range = 21-25 | 4.2 |
| 5 warps within range 26-30 | 0.4 |
| **Total** | **100** |

**Report 4.6b: Total length of yarn required to make one m² of cloth using different warp-weft ratios.**

| | |
|---|---|
| Assume finished width of cloth from loom m | 1 |
| Assume finished length of cloth m | 1 |
| Assume take up in the weft % | 10 |
| Assume take up in the warp % | 8 |
| Shrinkage of weft after washing cloth % | 6 |
| Shrinkage of warp after washing cloth % | 8 |
| Weft length therefore m | 1.16 |
| Length of warp therefore m | 1.16 |
| Assume warp tying off length m | 0.8 |
| **Length of warp therefore m** | **1.96** |

| Average diameter of yarns mm | 0.15 | 0.25 | 0.5 | 0.75 | 1 | mm |
|---|---|---|---|---|---|---|
| Av. warp count/m of 2,582 Amarna samples | 2,940 | 2,260 | 1,760 | 1,010 | 800 | per m |
| Av. weft count/m of 2,582 Amarna samples | 1,690 | 1,230 | 950 | 810 | 500 | per m |
| Length of weft thread to make 1 sq m of cloth | 1,960 | 1,427 | 1,102 | 940 | 580 | m |
| Length of warp thread to make 1 sq m of cloth | 5,762 | 4,430 | 3,450 | 1,980 | 1,568 | m |
| **Tot.length of yarn required to make 1 m²** | **7,722** | **5,857** | **4,552** | **2,920** | **2,148** | **m** |

**See Reports 3.15-3.17 below. Summary of the analysis in Report 4.16 below using source data from the database in Kemp 2001 Amarna Project: Workmens' Village Textiles. Warp and weft database of Amarna textiles. Accessed 21st April 2008. from http://www.amarnaproject.com/pages/recent_projects/material_culture/workmans.shtml**

| Diameter mm | Sample count | % | Warp count/cm | | Weft count/cm | |
|---|---|---|---|---|---|---|
| | | | Average | Median | Average | Median |
| LT 0.2 | 461 | 17.9 | 29.4 | 29 | 16.9 | 16 |
| 0.2-0.3 | 1760 | 68.2 | 22.6 | 22 | 12.3 | 12 |
| 0.4-0.6 | 346 | 13.4 | 17.6 | 18 | 9.5 | 9 |
| 0.6-0.9 | 15 | 0.6 | 10.1 | 8 | 8.1 | 7 |
| GT 0.9 | | | | | | |
| | **2582** | | | | | |

**Report 4.6c: Av. no. of warps and wefts using Amarna data**

| No. of warps using Amarna data | Median warps/m |
|---|---|
| 1 Av & median of no. warps range 0-10 | 2,940 |
| 2 Av & median of no. warps range 11-15 | 2,260 |
| 3 Av & median of no. warps range 16-20 | 1,760 |
| 4 Av & median of no. warps range 21-25 | 1,010 |
| 5 Av & median of no. warps range 26-30 | 800 |
| **No. of wefts using Amarna data** | **Median wefts/m** |
| 1 Av & median of no. wefts within warp range 0-10 | 1,690 |
| 2 Av & median of no. wefts within warp range 10-15 | 1,230 |
| 3 Av & median of no. wefts within warp range 16-20 | 950 |
| 4 Av & median of no. wefts within warp range 21-25 | 810 |
| 5 Av & median of no. wefts within warp range 26-30 | 500 |

**Report 4.6e: Percentage distribution of yarn diameters collated by socio-economic groupings**

| Socio-economic groupings | Percentage distribution of yarn diameters mm | | | | | Total | Area of cloth m² |
|---|---|---|---|---|---|---|---|
| | 0.15 | 0.25 | 0.5 | 0.75 | 1 | | |
| Socio-economic groups 1 | 35 | 55 | 9 | 1 | - | 100 | 1,502 |
| Socio-economic groups 2 | 29 | 60 | 10 | 1 | - | 100 | 1,775 |
| Socio-economic groups 3 | 16 | 72 | 11 | 1 | - | 100 | 10,675 |
| Socio-economic groups 4 | 14.9 | 71 | 12.9 | 1 | 0.2 | 100 | 49,840 |
| Socio-economic group 5 | - | 10 | 30 | 45 | 15 | 100 | 154,781 |
| | | | | | | | 218,573 |

**Report 4.6f: Area of cloth collated by yarn diameters and socio-economic groupings**

| Socio-economic groupings | Egypt: Area of cloth collated by average yarn diameter mm. | | | | | Egypt: Area of cloth m² | Cyprus: Area of cloth collated by average yarn diameter mm. | | | | | Cyprus: Area of cloth m² |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0.15 | 0.25 | 0.5 | 0.75 | 1 | | 0.15 | 0.25 | 0.5 | 0.75 | 1 | |
| Socio-economic groups 1 | 526 | 826 | 135 | 15 | - | 1,502 | 554 | 870 | 142 | 16 | - | 1,582 |
| Socio-economic groups 2 | 515 | 1,065 | 178 | 18 | - | 1,776 | 543 | 1,123 | 187 | 19 | - | 1,872 |
| Socio-economic groups 3 | 1,708 | 7,686 | 1,174 | 107 | - | 10,675 | 1,813 | 8,158 | 1,246 | 113 | - | 11,330 |
| Socio-economic groups 4 | 7,426 | 35,386 | 6,429 | 498 | 100 | 49,840 | 7,767 | 37,009 | 6,724 | 521 | 104 | 52,125 |
| Socio-economic group 5 | - | 15,478 | 46,434 | 69,651 | 23,217 | 154,780 | - | 16,381 | 49,144 | 73,716 | 24,572 | 163,813 |
| **Totals** | **10,175** | **60,441** | **54,350** | **70,289** | **23,317** | **218,573** | **10,677** | **63,541** | **57,443** | **74,385** | **24,676** | **230,722** |

**Report 4.6d: Percentage split of yarn diameters.**

| Range yarn diameters mm (n=3,385) | Average yarn diam. mm | % |
|---|---|---|
| 0-0.2 | 0.15 | 14.9 |
| 0.2-0.3 | 0.25 | 71 |
| 0.4-0.6 | 0.5 | 12.9 |
| 0.6-0.9 | 0.75 | 1 |
| Greater Than 0.9 | 1 | 0.2 |
| | | 100 |
| From Amarna diameters spreadsheet n = | | **3,385** |

**Report 4.6g: Mean of warp and weft counts/m collated by yarn diameters n = 2,582**

| Av. yarn diam mm (n=2,582) | Median warps/m | Median wefts/m |
|---|---|---|
| 0.15 | 2,940 | 1,690 |
| 0.25 | 2,260 | 1,230 |
| 0.5 | 1,760 | 950 |
| 0.8 | 1,010 | 810 |
| 1 | 800 | 500 |

**Report 4.6h: Length of yarn collated by yarn diams and socio-economic groupings**

Total length km of yarn required for Egypt collated by socio-economic groups

| Yarn diams mm categories 1-5 | Egypt 0.15 | Egypt 0.25 | Egypt 0.5 | Egypt 0.75 | Egypt 1 | Cyprus 0.15 | Cyprus 0.25 | Cyprus 0.5 | Cyprus 0.75 | Cyprus 1 |
|---|---|---|---|---|---|---|---|---|---|---|
| Socio-economic groups 1 | 4,062 | 4,838 | 615 | 44 | - | 4,278 | 5,096 | 646 | 47 | - |
| Socio-economic groups 2 | 3,977 | 6,238 | 810 | 53 | - | 4,193 | 6,577 | 851 | 55 | - |
| Socio-economic groups 3 | 13,189 | 45,017 | 5,344 | 312 | - | 14,000 | 47,781 | 5,672 | 330 | - |
| Socio-economic groups 4 | 57,344 | 207,256 | 29,265 | 1,454 | 215 | 59,977 | 216,762 | 30,608 | 1,521 | 223 |
| Socio-economic group 5 | - | 90,655 | 211,368 | 203,381 | 49,870 | - | 95,944 | 223,703 | 215,251 | 52,781 |
| **Total length of yarn km** | **78,572** | **354,004** | **247,402** | **205,244** | **50,085** | **82,448** | **372,160** | **261,480** | **217,204** | **53,004** |
| | | | **Egypt - total length (km)** | | **935,307** | | | **Cyprus- total length (km)** | | **986,296** |

# Module 7. Weight kg of dry fbre required

**Report 4.7a: Weight of linen yarn correlating to Amarna yarns**

| Average Amarna diameters | 0.15 | 0.25 | 0.5 | 0.75 | 1 |
|---|---|---|---|---|---|
| Nearest modern equivalent | 160/3 | 130/3 | 50/3 | 20/3 | 18/3 |
| Muktiplying factor | 160 | 130 | 50 | 20 | 18 |
| Length of yarn to make 1 kg yarn | 32280 | 26228 | 10088 | 4035 | 3632 |
| Weight of one m of 3 ply yarn kg | 3.0979E-05 | 3.8127E-05 | 9.9128E-05 | 0.00024783 | 0.00027533 |
| Length of yarn to make 1 kg yarn | 32280 | 26228 | 10088 | 4035 | 3632 |
| Weight of one m of 3 ply yarn kg | 3.0979E-05 | 3.8127E-05 | 9.9128E-05 | 0.00024783 | 0.00027533 |

| Average diameters of the Amarna yarns | 0.15 | 0.25 | 0.5 | 0.75 | 1 |
|---|---|---|---|---|---|
| Length of yarn per kg of yarn (m/kg) | 32,280 | 26,228 | 10,088 | 4,035 | 3,632 |
| **Weight kg of one m of 3 ply yarn kgs** | **3.0979E-05** | **3.8127E-05** | **9.9128E-05** | **0.00024783** | **0.00027533** |

**Report 4.7d: Weight of yarn/flax fibre required to clothe 100,000 population sample**

| Weight of yarn/flax fibre required to clothe 100,000 people | Egypt | Cyprus |
|---|---|---|
| | Wt of yarn kg | Wt of yarn kg |
| Socio-economic groups 1 | 382 | 459 |
| Socio-economic groups 2 | 454 | 2,050 |
| Socio-economic groups 3 | 2,732 | 9,342 |
| Socio-economic groups 4 | 12,999 | 8,988 |
| Socio-economic group 5 | 88,543 | 104,242 |
| Total weight of yarn kg | **105,110** | **125,082** |
| Rounded to nearest 1000 | 105,000 | 125,000 |

| | | |
|---|---|---|
| 8/3 linen | 1614 | m/kg |
| 1/3 linen | 201.75 | m/kg |
| 50/3 linen | 10088 | m/kg |
| 40/2 = | 12,108 | m/kg |
| 1/2 linen | 302.7 | |
| Ratio 40/2 to 50/3 | 1.50037175 | |

| | | | | | |
|---|---|---|---|---|---|
| Diam inches | 0.0375 | 0.025 | 0.0189 | 0.014 | 0.012 |
| Dimeter mm | 0.9525 | 0.635 | 0.48006 | 0.3556 | 0.3048 |
| Linen classsification 3 ply | 18 | 30 | 50 | 80 | 100 |

| Average Amarna diameters | 0.15 | 0.25 | 0.5 | 0.75 | 1 |
|---|---|---|---|---|---|
| Estimated weight of one m of the Amarna two-ply yarns | 3.0979E-05 | 3.8127E-05 | 9.9128E-05 | 0.00024783 | 0.00027533 |

**Egypt**

| Egyptian Socio-economic groupings | Wt. of yarn collated by yarn diams. mm | | | | | Wt of yarn kg |
|---|---|---|---|---|---|---|
| | 0.15 | 0.25 | 0.5 | 0.75 | 1 | |
| Socio-economic groups 1 | 126 | 185 | 61 | 11 | - | 382 |
| Socio-economic groups 2 | 123 | 238 | 80 | 13 | - | 454 |
| Socio-economic groups 3 | 409 | 1,716 | 530 | 77 | - | 2,732 |
| Socio-economic groups 4 | 1,777 | 7,902 | 2,901 | 360 | 59 | 12,999 |
| Socio-economic group 5 | - | 3,456 | 20,952 | 50,404 | 13,731 | 88,543 |
| **Total weight of yarn kg** | **2,434** | **13,497** | **24,524** | **50,865** | **13,790** | **105,110** |

**Cyprus**

| Cypriot Socio-economic groupings | Wt. of yarn collated by yarn diams. mm | | | | | Wt of yarn kg |
|---|---|---|---|---|---|---|
| | 0.15 | 0.25 | 0.5 | 0.75 | 1 | |
| Socio-economic groups 1 | 133 | 251 | 64 | 12 | - | 459 |
| Socio-economic groups 2 | 130 | 1,822 | 84 | 14 | - | 2,050 |
| Socio-economic groups 3 | 434 | 8,265 | 562 | 82 | - | 9,342 |
| Socio-economic groups 4 | 1,858 | 3,658 | 3,034 | 377 | 61 | 8,988 |
| Socio-economic group 5 | | 14,189 | 22,175 | 53,346 | 14,532 | 104,242 |
| **Total weight of yarn kg** | **2,554** | **28,185** | **25,919** | **53,831** | **14,593** | **125,082** |

| Average diameter of yarns mm | 0.15 | 0.25 | 0.5 | 0.75 | 1 | mm |
|---|---|---|---|---|---|---|
| Tot.length of yarn required to make 1 sq m | 7,722 | 5,857 | 4,552 | 2,920 | 2,148 | **m** |
| Tot.length of yarn required to make 1 sq cm | 0.7722 | 0.5857 | 0.4552 | 0.292 | 0.2148 | m |
| Wt kg of one sq cm | 2.3922E-05 | 2.2331E-05 | 4.5123E-05 | 7.2367E-05 | 5.9141E-05 | m |
| Wt mg/ sq cm | 23.9 | 22.3 | 45.1 | 72.4 | 59.1 | $mg/cm^2$ |
| tex g/km | 31 | 38 | 99 | 248 | 275 | g/kg |

| | 40/3 | 40/2 | 16/2 | |
|---|---|---|---|---|
| Length of thread required to make one sq m cloth = | 3911 | 3911 | 3911 | $m/m^2$ |
| Length of 40/2 thread per kg of dry fibre = | 2000 | 12095 | 4900 | m/kg |
| Weight of dry fibre to make one sq m of linen cloth = | 1.956 | 0.323 | 0.798 | $kg/m^2$ |

# Module 8. Area of land required to grow flax

**Report 4.8c: Area required to meet the demand for linen cloth.**

| | | |
|---|---|---|
| Egyptian yield flax fibre Robino 1884: 432 | 627 | kg/ha |
| Egyptian yield flax fibre Caldwell 1931: 16 | 535 | kg/ha |
| Modern Messenia flax yield Robkin 1979: 472 | 804 | kg/ha |
| Reduction in yield pre fertilizers | 36 | % |
| % yield pre use of fertilisers | 64 | % |
| Egyptian yield of fibre | 342 | kg/ha |
| Assumed Cyprus yield | 342 | kg/ha |
| Area of land in Egypt required for production of flax | 308 | ha |
| Area of land in Cyprus required for production of flax | 308 | ha |
| Losses harvesting and transporting | 15 | % |
| Uplift for wastage in harvest and transport | 115 | |
| Area of land in Egypt required for production of flax | 355 | ha |
| Area of land in Cyprus required for production of flax | 355 | ha |

| | | |
|---|---|---|
| Seed rate (MacAdams 1847: 13) = | 126 | lbs/acre |
| Seed rate = | 141 | kg/ha |
| Av. yield of flax seed1 = | 557 | kg/ha |
| Total seed requirement = | 50,055 | kg |
| Area to grow seed corn = | **90** | ha |
| % of land for flax required for seed = | **25** | % |
| % of land for flax available for linseed oil= | **75** | % |
| Area for production = | 355 | ha |
| Seed rate = | 126 | lbs/acre |
| Seed rate = | 141 | kg/ha |
| Total flax fibre required = | 105,110 | kg |
| % of land for flax required for seed = | 25 | % |
| % of land for flax available for linseed oil= | 75 | % |

1 Barker 1917: 528, Table 2

| | |
|---|---|
| No. male adults/100,000 pop capable of lifting 22 kg = | 22,835 |

Flax ht of modern crops

| |
|---|
| 29.3 |
| 31.1 |
| 29.3 |
| 31 |
| 29.7 |
| 29.5 |
| 30.3 |
| 28.6 |
| 31.5 |
| 29.7 |

| | | | |
|---|---|---|---|
| Average | 30 | | |
| Median | 29.7 | | |
| Max | 31.5 | | |
| Min | 28.6 | | |
| Median + | 1.8 | | |
| Median - | 1.1 | % | |
| Av erage + | 1.5 | 5 | |
| Average - | 1.4 | | |

**Report 4.8b: Ethnographic evidence of flax yields kg/ha.**

Egyptian yield flax 1882. Ref Robino 1884: 432

| | | |
|---|---|---|
| Weight of flax = | 6,000 | tons |
| Area under cultivation = | 24,000 | acres |
| Yield = | 0.25 | tons/acre |
| Yield = | 560 | lbs/acre |
| 1 lb/acre = | 1.12 | kg/ha |
| Yield = | 627.2 | kg/ha |

US Flax-seed yields Statistics of the Department of Agriculture. Ref Barker 1917: 528, Table 2.

| Year | Bushels | Acres | Bushels / acre | kg/acre | kg/ha |
|---|---|---|---|---|---|
| 1889 | 10250 | 1319 | 7.77 | 196.8 | 486.3 |
| 1899 | 19979 | 2111 | 9.46 | 239.6 | 592.1 |
| 1902 | 29285 | 3740 | 7.83 | 198.3 | 490 |
| 1903 | 27301 | 3233 | 8.44 | 213.8 | 528.3 |
| 1904 | 23401 | 2264 | 10.34 | 261.9 | 647.2 |
| 1905 | 28478 | 2535 | 11.23 | 284.4 | 702.8 |
| 1906 | 25576 | 2506 | 10.21 | 258.6 | 639 |
| 1907 | 25851 | 2864 | 9.03 | 228.7 | 565.1 |
| 1908 | 25805 | 2679 | 9.63 | 243.9 | 602.7 |
| 1909 | 25856 | 2742 | 9.43 | 238.9 | 590.3 |
| 1910 | 12718 | 2467 | 5.16 | 130.7 | 323 |
| 1911 | 19370 | 2757 | 7.03 | 178.1 | 440.1 |
| 1912 | 28073 | 2851 | 9.85 | 249.5 | 616.5 |
| 1913 | 17853 | 2291 | 7.79 | 197.3 | 487.5 |
| 1914 | 13749 | 1645 | 8.36 | 211.8 | 523.4 |
| 1915 | 14030 | 1387 | 10.12 | 256.3 | 633.3 |
| 1916 | 15459 | 1605 | 9.63 | 243.9 | 602.7 |
| | Average = | | 117.2 | 225.4 | 557.1 |

| | | |
|---|---|---|
| Yield of green flax ref Caldwell 1931: 16 = | 80 | cwt/acre |
| | 8960 | lb/acre |
| | 10035 | kg/ha |
| Yield of green flax ref Caldwell 1931: 16 = | 535 | kg/ha |

**Units**

| | | |
|---|---|---|
| 1 bushel/acre flax = | 25.3293413 | |
| 1 ha = | 2.471 | acre |
| 1 acre = | 0.40469446 | ha |
| 1 lb/acre = | 1.12 | kg/acre |
| **1 cwt/acre =** | **125.4** | **kg/ha** |

**Report 4.8d: Percentage by yield of usable flax for linen production.**

| | | |
|---|---|---|
| Percentage remaining after losses | | 5.3 |
| **Activity. Source data Caldwell 1931: 16.** | **Yield kg/ha** | **% of initial weight** |
| Weight of green flax post harvest | 10,050 | |
| Weight after loss of water drying | 4,525 | 45.0 |
| Weight loss de-seeding | 905 | 9.0 |
| Weight loss retting | 905 | 9.0 |
| Less hackling and scutching | 3,180 | 31.7 |
| **Wt. of fibre ready for spinning** | **535** | **5.3** |
| | 10049 | |

| | | |
|---|---|---|
| 1 cwt = | 50.848 | kg |
| 1 acre = | 0.4047 | ha |
| 1 cwt/acre = | 125.64 | kg/ha |
| 1 lb = | 0.454 | kg |
| 1 acre = | 0.4047 | ha |
| 1 lb/acre = | 1.12181863 | kg/ha |

**Report 4.8e: Manpwer requirements for rippling**

| | | |
|---|---|---|
| Total weight of green flax (to nearest 1000) | 1,983,213 | kg |
| Average weight of one handful = | 0.36 | kg |
| Total no. of handfuls = | 5,509,000 | |
| Time taken/ handful = | 45 | secs |
| Total time = | 68,863 | hrs |
| Assume 9 hr day = | 7,651 | days |
| Assume no available days = | 347 | |
| Equivalent workload = | 23 | man-years |

**Report 4.8f: Estimate in no. of man-days carrying flax bales**

| | | |
|---|---|---|
| Man Days for tying bales from Report 4.8g | 2 | |
| Total wt of fibre required | 105,110 | kg |
| Factor | 19 | |
| Total weight of bales carried | 1,983,213 | kg |
| Estimated weight of dry bale | 21 | kg |
| No. of dry bales carried | 94,439 | |
| No. of bales carried/hr/man from field to river | 5 | |
| No. of man hrs carrying dry from field to river | 18,888 | hrs |
| Estimated weight of wet bales | 42 | kg |
| No. of wet bales carried | 94,439 | |
| No. bales carried/hr/pair of men from river to drying area | 3 | |
| No. of wet bales carried | 94,439 | |
| No of men required/bale | 2 | |
| No. of man hrs carrying dry from river to bank | 188,877 | |
| Total man hrs | 207,765 | |
| Assume no. of hours worked per day | 9 | |
| Total no. of man days | 23,086 | |
| Rounding to nearest 100 | 23,100 | |
| Assume working days available per year | 347 | |
| Workload to carry bales | 67 | |
| Workload to tie and carry bales | **69** | |

**Report 4.8g: Manpwer requirements for tying up bales**

| | | |
|---|---|---|
| Total weight of green flax = | 1,983,213 | kg |
| Tot. no. of dry bales (Report 4.8f) | 94,439 | kg |
| Assume no.of bales tied per hour | 30 | |
| No. of hours tying = | 3148 | hrs |
| Assume working hours/day = | 9 | hrs |
| No. working days = | 350 | days |
| Assume no available days = | 147 | |
| Equivalent full time workers = | 2 | man-years |

# Module 9. Manpower required to grow flax

| | | |
|---|---|---|
| Available days | 308 | days/yr |
| Ploughing case | 242 | man-days/ha |
| Hoeing case | 304 | man-days/ha |
| Ploughing case | 0.7857 | man-years/ha |
| Hoeing case | 0.9870 | man-years/ha |

**Report 4.9a: Man-days dedicated to flax production using ploughing.**

| | | |
|---|---|---|
| First ploughing man-days/ha | 12 | |
| Second ploughing man-days/ha | 6 | |
| Tertiary ploughing man-days/ha | 5 | |
| Sowing estimate man-days/ha | 3 | |
| Harrowing man-days/ha | 5 | |
| Weeding estimate man-days/ha | 27 | |
| Harvesting man-days/ha | 13 | |
| Irrigation man-days/ha | 171 | Reflects flax has a higher requirement for water than cereals or pulses |
| **Tot. agricultural man-days/ha** | **242** | |

| | | | |
|---|---|---|---|
| **Assume Egypt ploughing 70% and Hoeing 30%** | **285.4** | **Assume Cyprus ploughing 30% and Hoeing 70%** | **260.6** |

**Report 4.9b: Man-days dedicated to flax production using hoeing for seed preparation.**

| | |
|---|---|
| Hoeing man-days/ha | 83 |
| Sowing estimate man-days/ha | 3 |
| Harrowing man-days/ha | 7 |
| Weeding estimate man-days/ha | 27 |
| Harvesting man-days/ha | 13 |
| Irrigation man-days/ha | 171 |
| **Total agricultural man-days/ha** | **304** |

Apparent productivity gain 20 %

**Report 4.9c: Workload to grow flax using hoeing as the means to cultivate soil**

| Manpower requiremenets | Egypt | |
|---|---|---|
| Area of land under flax cultivation | 355 | ha |
| **No. of man-days required** | **107,920** | **man-days** |
| Available days after sickness/festivals etc. | 308 | days |
| **Manpower requirement to cultivate flax** | **350** | **people** |

**Report 4.9d: Ethnographic evidence for ploughing rates in Egypt.**

**Reference Richards 1982: Table 2.1, 17.**

| | | |
|---|---|---|
| Irrigation of land for flax in 1813 A.D. = | 72 | man-days/feddan |
| Irrigation of land for flax in 1813 A.D. = | 171.4 | man-days/ha |
| 1 feddan = | 0.42 | ha |

**Report 4.9e: Workload to grow flax using ploughing as the means to cultivate soil**

| Manpower requiremenets | Egypt | |
|---|---|---|
| Area of land under flax cultivation | 355 | ha |
| **No. of man-days required** | **85,910** | **man-days** |
| Available days after sickness/festivals etc. | 308 | days |
| **Manpower requirement to cultivate flax** | **279** | **people** |

**Report 4.9f: Workload to grow flax using ploughing as the means to cultivate soil**

| Manpower requirements | Egypt | |
|---|---|---|
| Ploughing assumption | 30 | % |
| Hoeing assumption | 70 | % |
| **Manpower requirement to cultivate flax** | **329** | **people** |

**Report 4.9g: Days available per annum for cloth processing.**

| | | |
|---|---|---|
| Available days after sickness, festivals for cloth processing | **347** | days |
| Diffence in days lost between farming and cloth processing | **39** | days |

**Report 4.9h: Classical evidence for harvesting flax ref Columella de r.r. 2.12.**

| | | |
|---|---|---|
| Time to plough one iugerum of land = | 3 | days/iugerum |
| One iugerum = | 0.25 | ha |
| Time to pull one ha of flax = | 0.0833 | days/ha |
| Time to pull one ha of flax = | 13 | days |

**Report 4.9i - Number of sheaves in a bale.**

| | | |
|---|---|---|
| Average diameter of a flax stalk = | 0.325 | cm |
| Area of average flax stalk = | 0.08297 | sq cm |
| Assume side of square = | 33 | sq cm |
| Area of sqaure = | 1089 | sq cm |
| No. of stalks = | 10310 | |
| Total area of these stalks = | 855 | sq cm |
| % area of flax stalks = | 79 | % |
| Assume mans handfull of flax = | 3.6 | cm diam. |
| Area of handful = | 10.18 | sq. cm |
| Area of stalks in handful less air = | 8.04 | sq. cm |
| Diam of bale of flax = | 25 | cm |
| Area of flax bale = | 491 | sq cm |
| No. of sheaves = | 61.07 | |

**Report 4.9j: Available days for cloth workers and farmers**

| | Festival days | | | | | | Total |
|---|---|---|---|---|---|---|---|
| Months | 1 | 2 | 3 | 4 | 5 | 6 | |
| No. of festivals | 7 | 11 | 1 | 5 | 5 | 3 | 32 |
| Months | 7 | 8 | 9 | 10 | 11 | 12 | |
| No. of festivals | 6 | 2 | 6 | 2 | 2 | 3 | 21 |
| | | | | | | **12 months total** | **53** |

| | |
|---|---|
| % of festivals celebrated by farmers and days therefore lost to farming = | 12 |
| No. of days lost to festivals = | 6 |
| No. of days lost to sickness = | 15 |
| **Days available for farming after taking out sickness and festivals =** | **344** |
| **Egypt** | |
| Days lost for day off every 10 days | 36 |
| Net days available for farming = | **308** |
| **Cypriot/Cypriot** | |
| Days lost to the bad weather = | 36 |
| **Net days available for farming =** | **308** |

**Report 4.9k: Available days for cloth workers**

| | | |
|---|---|---|
| Festivals | 6 | |
| Sickness | 12 | Assumes 3 days less than working in the fields |
| | 0 | |
| **Working days** | **347** | |

# Module 10. Manpower required un the husbandry of sheep

**Report 4.10a: Preparation of wool.**

| | | |
|---|---|---|
| **Washing sheep** | | |
| Workers required to wash and constrain a sheep | 3 | |
| Hours worked per day | 9 | |
| No. of sheep washed per hour | 12 | |
| Total number of hours washing to nearest 1000 | 13,073 | hours |
| Total man-days rounded to nearest 1000 | 39,219 | man-hours |
| Available days for working | 347 | days |
| Utilised washing workload | 13 | man-years |
| **Plucking** | | |
| Weight of fibre required | 105,110 | kg |
| Weight wool plucked/animal | 0.75 | kg |
| Wastage rate | 10.5 | % |
| Yield of wool less 10.5% wastage | 0.67 | kg |
| Sheep required to clothe 100,000 poulation | 156,881 | |
| Number of sheep that can be plucked/day | 25 | |
| Number of workers per animal | 3 | |
| Number of days required (rounded to nearest 100) | 18,800 | days |
| Available days for working | 347 | days |
| Workload | 55 | man-days |

| **Combing** | **Max** | | **Min** | |
|---|---|---|---|---|
| Hours taken to card wool from 1 sheep | 15 | hrs | 10 | hrs |
| Ratio of efficiency modern carding to combing | 1.3 | | 130 | % |
| Ratio of modern to ancient wool obtained per sheep | 0.38 | | 0.38 | |
| Hours taken to comb rather than card wool from 1 sheep | 7.4 | | 4.9 | |
| Total number of days to comb wool to nearest 100 | 129,000 | days | 85,400 | days |
| Available days for working | 347 | days | 347 | days |
| Combing workload | 372 | man-years | 246 | man-years |

**Report 4.10c: Volume of a bale of one Mycenaean LANA**

| | | |
|---|---|---|
| Diam. of wool from one Soay sheep rolled up = | 0.18 | m |
| Area. of wool from one Soay sheep rolled up = | 0.025451 | $m^2$ |
| Length of wool roll = | 0.3 | m |
| Volume of the wool from one Soay sheep rolled up = | 0.007636 | $m^3$ |
| Weight of wool from one Soya sheep | 0.454 | kg |
| Weight of wool from one Mycenaean sheep = | 0.75 | kg |
| Weight of one LANA of wool = | 3 | kg |
| No. of Soay sheep to privide one LAN wool = | 6.6 | |
| Volume of a bale of one LANA = | 0.050398 | $m^3$ |
| Size of equal sided bale of the same volume = | 0.37 | m |

Source date of Soay sheep Ryder 1983: 708.

**Report 4.10d: Spinning of wool (Cyprus)**

| | | |
|---|---|---|
| Weight of wool to be spun | 125,082 | kg |
| Spinning rate | 2.5 | hrs/oz |
| Spinning rate | 88.2 | hrs/kg |
| Hours worked per day | 7 | |
| Total number of days to comb wool (rounded to nearest 1000) | 1,576,000 | days |
| Available days for spinning | 347 | |
| Spinning workload (rounded to nearest 10) | 4,540 | people |

**Report 4.10b: Husbandry of sheep**

| | |
|---|---|
| No. of sheep | 156,881 |
| Size of herd | 100 |
| **No. of shepherds** | **1,569** |

| Preparation of woolen fibre for spinning | |
|---|---|
| Washing sheep | 13 |
| Plucking wool off the sheep | 55 |
| Combing the wool for spinning | 372 |
| **Total man-years** | **440** |

| Cypriot wool production | Workers required | Egyptian flax production | Workers required | | |
|---|---|---|---|---|---|
| Process | | Process | All hoeing | All ploughing | 70% hoeing 30% ploughing |
| Husbandry of flocks | 1,569 | Cultivation | 350 | 279 | 329 |
| Preparation of fibre | 440 | Preparation of fibre | 342 | 342 | 342 |
| **Total** | **2,009** | **Total** | **692** | **621** | **671** |
| | | Ratio Cyprus to Egypt | **2.9** | **3.2** | **3.0** |

| Sheep required to clothe 100,000 popul'n | 156,881 |
|---|---|
| Size of flocks assumed | 100 |
| Number of flocks | 1,569 |
| Number of shepherds | 1,569 |

**Report 4.10e**

| Cypriot wool production | Workers required | Egyptian flax production | Workers required | | |
|---|---|---|---|---|---|
| Process | | Process | Hoeing | Ploughing | Assume for Egypt 70% hoeing 30% ploughing |
| Husbandry of flocks | 1,569 | Cultivation | 350 | 279 | 329 |
| Preparation of fibre | 440 | Preparation of fibre | 342 | 342 | 342 |
| Spinning | 4,540 | Spinning | 10,372 | 10,372 | 10,372 |
| Weaving | 3,620 | Weaving | 3,620 | 3,620 | 3,620 |
| **Total** | **10,169** | **Total** | **14,684** | **14,613** | **14,663** |
| | | Ratio Egypt to Cyprus | **1.444** | **1.437** | **1.442** |

**Report 4.10d: Minoan duodecimal system**

| Zakros | Mochlos | Knossos |
|---|---|---|
| 1421.3 | 1458.1 | 1567.47 |
| Average 3 weights = | | 1482.3 |
| One LANA equiv. = | | 2964.6 |

**Report 4.10e: Roving of fibre**

Ref Petzel 1987: 16 citing Waetzoldt 1972.

| | | |
|---|---|---|
| Weight of wool to be spun | 125,082 | kg |
| Processing rate min | 1.01 | kg/day |
| Processing rate min | 1.51 | kg/day |
| Roving min | 126,333 | days |
| Roving max | 188,873 | days |
| Roving min. assuming 347 working days/yr | 364 | man-years |
| Roving max. assuming 347 working days/yr | 544 | man-years |
| Av. roving rate assuming 347 working days/yr | 454 | man-years |

# Module 11. Manpower to prepare fibre for spinning

**Report 4.11a: Experimental archaeology - hacking and skutching**

| | | |
|---|---|---|
| Man -years rippling = | 23 | man-years |
| Man-years tying up bales, carrying bales, and retting = | 69 | man-years |
| Average weight of a sample of 11 handfuls = | 0.36 | kg |
| % of useable fibre for cloth production = | 5.3 | |
| Wt of suitable fibre = | 0.0191 | kg |
| Number of handfuls to make 1 kg fibre = | 52.4 | |
| Estimated time of breaking flax per handful = | 2 | min |
| Estimated time of scutching flax per handful = | 2.5 | min |
| Estimated time of hackling flax per handful = | 4 | min |
| Total time to process flax = | **8.5** | **min** |
| Total time to produce 1 kg fibre = | 7.42 | hrs |
| Total fibre requirement (rounded to nearest 1000) = | 105,110 | kg |
| Number of hours worked per working day = | 9 | hrs |
| Time to produce tot. fibre requir't (to nearest 1000) = | 86,658 | man-days |
| Available days/yr less festivals/sickness etc. = | 347 | days |
| Tot no. of persons to for skutcking and hackiling = | **250** | man-years |
| Total man-years expended preparing flax = | **342** | man-years |

| Operation | Man-years |
|---|---|
| Rippling | 23 |
| Binding and retting | 69 |
| Skutching and hackling | 250 |
| **Total** | **342** |

**Report 4.11b: Experimental archaeology: weight of plant samples.**

| **Av. wt of handful of flax and equivalent bast plant material** | | |
|---|---|---|
| Equivalent bast nettles and plant material | 0.345 | kg |
| | 0.3575 | kg |
| | 0.34 | kg |
| | 0.355 | kg |
| | 0.355 | kg |
| | 0.36 | kg |
| | 0.35 | kg |
| | 0.371 | kg |
| | 0.368 | kg |
| Flax samples 2007 harvest | 0.38 | kg |
| | 0.358 | kg |
| | 0.36 | kg |
| Average = | **0.36** | kg |
| Standard deviation = | 0.011 | |
| 95% confidence limit = | 0.006 | |
| No of sheaves/bale = | 60 | |
| Weight of bale = | 21 | kg |

**Report 4.11c: Time to splice single thread and spindle spin two ply yarn**

Ref Tiedeman and Jakes

| | |
|---|---|
| Thigh spinning rate 1 | 0.127 |
| Thigh spinning rate 2 | 0.101 |
| Thigh spinning rate 3 | 0.159 |
| Average m/min | 0.129 |
| Time to thigh spin one m (mins) | 7.75 |

| | | |
|---|---|---|
| Assuming splice length to bast length = | 7.2 | % |
| Time to thigh spin fibre/m of cloth = | 0.558 | min/m |

**Report 4.11d: Manpower required to spin yarn (flax for Egypt and wool for Cyprus)**

| | | |
|---|---|---|
| Splicing rate for thigh spinning single yarn = | 0.558 | min/m |
| Plying rate for spindle spinning into 2 ply yarn = | 0.5 | min/m |
| Total time to produce 2 ply yarn = | 1.616 | min/m |

| | **Egypt** | **Cyprus** |
|---|---|---|
| Area of cloth to be produced $m^2$ | 218,573 | 230,722 |
| Total length of thread required km | 935,307 | 986,296 |
| Total length of thread required m | 935,307,000 | 986,296,000 |
| Total time to spin thread min | 1,511,456,112 | 1,593,854,336 |
| Effective hours worked/day for women hrs | 7 | 7 |
| ıanpower required (rounded to nearest 1000) man-days | 3,599,000 | 3,795,000 |
| Available days/yr less festivals/sickness etc. days | 347 | 347 |
| **Tot. no. of workers required to spin yarn** | **10,372** | **10,937** |

# Module 12. Manpower required for weaving

**Report 4.12a: Total people required to warp the looms to produce domestic clothing for 100,000.**

| | Egypt | Cyprus |
|---|---|---|
| Area of cloth to be produced $m^2$ | 218,573 | 230,722 |
| Width of cloth produced on loom after shrinkage m | 1 | 1 |
| Total length of cloth m | 218,573 | 230,722 |
| Length of cloth produced per loom m | 2 | 2 |
| Area of cloth made between each warpping $m^2$ | 2 | 2 |
| Number of times the looms have to be re-warped | 109,287 | 115,361 |
| Time taken to re-warp the loom days | 1 | 1 |
| Available days/yr for production | 347 | 347 |
| **Equiv. full time workers to warp the looms** | **315** | **332** |

**Report 4.12b: Area of cloth collated by cloth quality to clothe 100,000 people in domestic clothing**

| Area of cloth | Socio-economic groups | Popul'n | Egypt area of cloth $m^2$ | Cyprus area of cloth $m^2$ |
|---|---|---|---|---|
| Area of second class cloth | 1 & 2 | 440 | 1,502 | 3,453 |
| Area of third class cloth | 3 | 2,530 | 12,450 | 11,330 |
| Area of fourth class cloth | 4 | 10,000 | 49,840 | 52,125 |
| Area of ration quality fourth class cloth | 5 | 87,030 | 154,781 | 163,813 |
| **Total** | | **100,000** | **218,573** | **230,721** |

**Report 4.12c: No. of days required to weave one sq m cloth**

| Class of cloth | Width of finished cloth m | Area of cloth woven $m^2$ /day | No. of days/$m^2$ | No. of weavers | Total man-days/$m^2$ cloth |
|---|---|---|---|---|---|
| Second class cloth | 1 | 0.08 | 12.5 | 2 | 25 |
| Third class cloth | 1 | 0.25 | 4 | 3 | 12 |
| Fourth class cloth | 1 | 0.333 | 3 | 3 | 9 |
| Ration quality 4th class cloth | 1 | 0.5 | 2 | 2 | 4 |

**Report 4.12d: Beverly Lee, Fishbourne Palace 10th Sept**

| | | |
|---|---|---|
| Width | 0.9 | m |
| Length/day | 0.8 | m |
| Area of cloth/day | 0.72 | $m^2$/day |
| Warps/m | 700 | |
| Wefts/m | 630 | |
| No. of weavers | 2 | |
| Total man-days/$m^2$ | 2.8 | |

**Report 4.12e: Total worker days required to weave sufficient cloth to clothe 100,000 people**

| Class of cloth | Egypt | | | Cyprus | | |
|---|---|---|---|---|---|---|
| | 1. Area of cloth $m^2$ | 2. Tot. man days /$m^2$ of cloth | Tot. man-days required | 1. Area of cloth $m^2$ | 2. Tot. man days /$m^2$ of cloth | Tot. man-days required |
| Second class cloth | 1,502 | 25 | 37550 | 3,453 | 25 | 86325 |
| Third class cloth | 12,450 | 12 | 149400 | 11,330 | 12 | 135960 |
| Fourth class cloth | 49,840 | 9 | 448560 | 52,125 | 9 | 469125 |
| Ration quality 4th class cloth | 154,781 | 4 | 619124 | 163,813 | 4 | 655252 |
| **Total workload** | **218,573** | | **1,254,634** | **230,721** | | **1,346,662** |
| No of days available for work | | | 347 | | | 347 |
| **Total man-days required** | | | **3,616** | | | **3,881** |
| **Total workload rounded to nearest 10** | | | **3,620** | | | **3,880** |

# Total manpower required to meet the demand for cloth

**Report 4.12f: Total workload in man-years required to produce linen cloth for domestic clothing. Case A: hoeing**

| Total workload to produce cloth to clothe 100,000 people | Egypt | |
|---|---|---|
| Egyptian flax product'n man-years vs Cyprus husbandry requirements | 350 | man-days |
| Total no. of man-years required to prepare fibre for spinning | 342 | man-days |
| Total number of man-years required to spin yarn | 10,372 | man-days |
| Total number of man-years required to weave cloth | 3,616 | man-days |
| Total number of man-years | 14,680 | man-days |
| Total area of cloth required/yr/100,000 people | 218,573 | $m^2$ |
| No. of man-years of cloth makers required per $m^2$ of cloth | 24.51 | man-years/$m^2$ |

**Report 4.12g: Total workload in man-years required to produce linen cloth for domestic clothing. Case B: Egypt ploughing.**

| Total workload to produce cloth to clothe 100,000 people | Egypt | |
|---|---|---|
| Egyptian flax product'n man-years vs Cyprus husbandry requirements | 279 | man-days |
| Total no. of man-years required to prepare fibre for spinning | 342 | man-days |
| Total number of man-years required to spin yarn | 10,372 | man-days |
| Total number of man-years required to weave cloth | 3,616 | man-days |
| Total number of man-years | 14,609 | man-days |
| Total area of cloth required/yr/100,000 people | 218,573 | $m^2$ |
| No. of man-years of cloth makers required per $m^2$ of cloth = | 24.4 | man-years/$m^2$ |

**Report 4.12h: Total man-years required to produce linen cloth vs Cypriot woolen cloth production for domestic clothing. Case C: Egyptian 70% hoeing and 30% ploughing.**

| Total workload to produce cloth to clothe 100,000 people | Egypt | Cyprus | | | Ratio Egypt to Cyprus | Ratio Cyprus to Egypt |
|---|---|---|---|---|---|---|
| Egyptian flax product'n man-years vs Cyprus husbandry requirements | 329 | 1,569 | man-years | | 0.21 | 4.77 |
| Total no. of man-years required to prepare fibre for spinning | 342 | 440 | man-years | | 0.78 | 1.29 |
| Total number of man-years required to spin yarn | 10,372 | 4,540 | man-years | | 2.28 | 0.44 |
| Total number of man-years required to weave cloth | 3,616 | 3,881 | man-years | | 0.93 | 1.07 |
| Total number of man-years | 14,659 | 10,430 | man-years | | 1.41 | 0.71 |
| Total area $m^2$ of cloth required/yr/100,000 people | 218,573 | 230,721 | | Overall ratio | 1.48 | 0.68 |
| No. of man-years per $m^2$ of cloth required | 24.5 | 16.6 | | | | |

**Report 4.12i: Total manpower required to support cloth production for the total population of Egypt and Cyprus**

| Manpower required to support the domestic cloth industry | Egypt | Cyprus |
|---|---|---|
| Population of Egypt | 2,200,000 | 150,000 |
| Population million | 2.2 | 1.5 |
| Sample size | 100,000 | 100,000 |
| Scaling factor | 22 | 1.5 |
| **Total number of individuals producing cloth** | **322,498** | **15,645** |

**Report 4.12j: Percentage breakdown of manpower collated by process**

| % breakdown of manpower collated by process | Egypt | Cyprus |
|---|---|---|
| No. of man-years required to cultivate flax | 2.2 | 15.1 |
| Tot. no. of man-years req'red to prepare flax for spinning | 2.3 | 4.2 |
| Total number of man-years required to spin yarn | 70.8 | 43.5 |
| Total number of man-years required to weave cloth | 24.7 | 37.2 |
| Total number of man-years required to weave cloth | **100.0** | **100.0** |

**Report 4.12k: Summary of essential man-years for housing, food, and clothes**

| Allocation of manpower | Egypt | Cyprus |
|---|---|---|
| Agriculture | 37,205 | 47,490 |
| Domestic housing | 920 | 920 |
| Cloth | 14,659 | 10,430 |
| Pottery | 66 | 66 |
| Tot. workforce supporting basic needs | 52,850 | 58,906 |
| Non-productive (age 0-5 or +55) | 30,860 | 30,860 |
| Elite socio-economic groups 1-3 | 2,970 | 2,970 |
| Surplus for making value-add goods | 13,320 | 7,264 |
| Total | 100,000 | 100,000 |

**Report 4.12j: Sensitivity Analysis**

| Wear and Tear: All items of clothing wear out in 3.5 years | Egypt | Cyprus |
|---|---|---|
| Cloth workers assuming different wear and tear rates for different socio-economic groups | 14,659 | 10,430 |
| Cloth workers assuming same wear and tear rate of 3.5 years/year for all socio-economic groups | 15,757 | 11,129 |
| Increase | 1,098 | 699 |
| **Percentage increase** | **7.5** | **6.7** |

| Wear and Tear: All items of clothing wear out in 7.5 years | Egypt | Cyprus |
|---|---|---|
| Cloth workers assuming different wear and tear rates for different socio-economic groups | 14,659 | 10,430 |
| Cloth workers assuming same wear and tear rate of 7.5 years/year for all socio-economic groups | 7,963 | 5,622 |
| Increase | -6,696 | -4,808 |
| **Percentage decrease** | **-45.7** | **-46.1** |

1.1698016

# Module 13: Prices of common garments known from Deir el-Medina ostraca

**Report 4.13a: Price per unit area of cloth**

| Garment | Price Copper Deben | | Area of cloth m² | | Price deben/m² | |
|---|---|---|---|---|---|---|
| | Low | High | Small | Large | Small | Large |
| Bag-tunic | 5 | 5 | 1.48 | 2.55 | 0.3 | 0.51 |
| Cloak | 20 | 25 | 2.24 | 3.21 | 0.11 | 0.13 |
| Shawl | 5 | 15 | 0.56 | 1.54 | 0.11 | 0.1 |
| Sash | 5 | 5 | 0.21 | 0.5 | 0.04 | 0.1 |
| Kerchief | 8 | 15 | 0.32 | 0.9 | 0.04 | 0.06 |
| Loin cloth | 15 | 25 | 0.45 | 0.45 | 0.03 | 0.02 |

**Report 4.13b: Man-days to produce cloth alone per garment**

| Garment | Area of cloth m² | | Man-days for cloth | |
|---|---|---|---|---|
| | Small | Large | Small | Large |
| Bag-tunic | 1.48 | 2.55 | 36.3 | 62.5 |
| Cloak | 2.24 | 3.21 | 54.9 | 78.7 |
| Shawl | 0.56 | 1.54 | 13.7 | 37.7 |
| Loin cloth | 0.45 | 0.45 | 11 | 11 |
| Kerchief | 0.32 | 0.9 | 7.8 | 22.1 |
| Sash | 0.21 | 0.5 | 5.1 | 12.3 |

**Report 4.13c: Equivalent values of a bag-tunic from Deir el-Medina**

| | | | | |
|---|---|---|---|---|
| Dry density barley | 609 | kg/m³ | | |
| Dry density wheat | 769 | kg/m³ | | |
| Vol of khar grain | 76.8 | litres | | |
| Value of tunic | 5 | deben | | |
| Exchange rate in New Kingdom | 2 | khar/deben | | |
| Equivalent value of tunic | 2.5 | khar | | |
| Volume of 2.5 khar | 192 | litres | | |
| 1 litre | 0.001 | m³ | | |
| Volume of 2.5 khar | 0.192 | m³ | | |
| Dry weight of 2.5 khar of barley | 117 | Kg | | |
| Dry weight of 2.5 khar of wheat | 148 | Kg | | |
| Kcals of barley and wheat consumed in Egypt | 64,807 | million kcals/yr/100,000 people | Rounded down to = | 64,800 |
| Children under 3 assumed breastfed | 15,080 | per 100,000 people | | |
| Population over 3 | 84,920 | per 100,000 people | | |
| Av. kcals of grain consumed in Egypt | 2,091 | kcals/day/individual | | |
| Size of nucleat family less one breast fed baby | 5 | | | |
| Kcals consumed of grain/nucleate family | 10,455 | kcals/day/family | | |
| Kcals of grain | 3,320 | kcals/kg | | |
| Energy from 2.5 khar barley | 388,440 | kcals | | |
| Energy from 2.5 khar wheat | 491,360 | kcals | | |
| Equivalent days food supply for barley case | 37 | days | | |
| Equivalent days food supply for wheat case | 47 | days | | |
| Equivalent weeks food supply for barley case | 6 | days | | |
| Equivalent weeks food supply for wheat case | 7 | days | | |

| | | |
|---|---|---|
| Area of a bag-tunic | 2.55 | m² |
| High case man-years to produce one m² flaxen cloth | 24.5 | man-days/m² |
| Additional uplift for washing, cutting and stitching | 5 | man-days/ |
| Man-years to make large bag-tunic high case | **67** | man-days |
| Value of tunic | **5** | deben |
| Man-years to make 5 copper deben | **95** | man-years |

**Report 4.14a: Analysis of the relationship of yarn weight, ply, length/unit length, packing factor, cross sectional area, and diameter**

| | | | |
|---|---|---|---|
| | | Packing factor = | 0.85 |
| One lea = 300 | yards/lb | Density of linen = | 1.58 g/cm$^3$ |
| | | | 1580 kg/m$^3$ |

| Count | Ply | yds/lb | m/kg | kg/m | Area mm$^2$ | Diameter mm |
|---|---|---|---|---|---|---|
| 5 | 2 | 750 | 1,514 | 0.00066072 | 0.418177332 | 0.858 |
| 10 | 2 | 1,500 | 3,027 | 0.00033036 | 0.209088666 | 0.607 |
| 15 | 2 | 2,250 | 4,541 | 0.00022024 | 0.139392444 | 0.496 |
| 20 | 2 | 3,000 | 6,054 | 0.00016518 | 0.104544333 | 0.429 |
| 30 | 2 | 4,500 | 9,081 | 0.00011012 | 0.069696222 | 0.35 |
| 40 | 2 | 6,000 | 12,108 | 8.259E-05 | 0.052272167 | 0.303 |
| 50 | 2 | 7,500 | 15,135 | 6.6072E-05 | 0.041817733 | 0.271 |
| 60 | 2 | 9,000 | 18,162 | 5.506E-05 | 0.034848111 | 0.248 |
| 10 | 3 | 1,000 | 2,018 | 0.00049554 | 0.313632999 | 0.743 |
| 15 | 3 | 1,500 | 3,027 | 0.00033036 | 0.209088666 | 0.607 |
| 20 | 3 | 2,000 | 4,036 | 0.00024777 | 0.1568165 | 0.526 |
| 30 | 3 | 3,000 | 6,054 | 0.00016518 | 0.104544333 | 0.429 |
| 40 | 3 | 4,000 | 8,072 | 0.000123885 | 0.07840825 | 0.372 |
| 50 | 3 | 5,000 | 10,090 | 9.9108E-05 | 0.0627266 | 0.332 |
| 60 | 3 | 6,000 | 12,108 | 8.259E-05 | 0.052272167 | 0.303 |
| 80 | 3 | 8,000 | 16,144 | 6.19425E-05 | 0.039204125 | 0.263 |

**Report 4.14b: Data and analysis of textile household items from Deir el-Medina used in Report 4.1b.**

| Household items | Area m$^2$ | | | References and remarks | |
|---|---|---|---|---|---|
| | Large | Medium | Small | | |
| Sheets | 19.8 | 15.1 | 5.4 | *Janssen 1995: 391-392. Tomb of Hatnofre had three linen chests with 76 sheets ranging in size from 16.5 to 4.5 m. It is assumed width in m = | 1.2 |
| Blankets | 2.1 | 2 | 1 | Killen 2003: X from measurement of extant beds shows average height of male adult m (average width assumed same as sheets) = | 1.71 |
| Textiles | 2 | 1 | 0.5 | | |
| Bags | 2 | 1 | 0.19 | Small bag originally carried corn 0.36 x 0.26 m, Cat No. 223. Collection of the National Museum of Antiquities Leiden. Hooft 1994: 100, Plate 10. | |

* In the Tomb of Kha and Merit sheets measured 4.15 x 1.2m, 4 x 4m and 2.2m (Roveri 2001: 31.)

| Refs for V Neck Dresses Vogelsang-Eastwood 1993: 123, Table 1. * Digital Egypt's Petrie Museum Deshasheh dress ca, 2800 B.C. UC 31182 & UC 31183 | | | | | | | | | | | | * | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Length shoulder to hem | 0.76 | 0.72 | 0.81 | 0.74 | 1.03 | 1.22 | 1.39 | 1.52 | 1.07 | 1.42 | 1.56 | | 1.11 |
| Depth bodice from shoulder DB | 0.13 | 0.12 | 0.19 | 0.13 | 0.13 | 0.22 | 0.22 | 0.2 | 0.17 | 0.3 | 0.25 | 0.5 | 0.21 |
| Length of skirt LS | 0.63 | 0.6 | 0.62 | 0.61 | 0.9 | 1 | 1.17 | 1.32 | 0.9 | 1.12 | 1.31 | 1.32 | 0.96 |
| Width of skirt WS | 0.54 | 0.44 | 0.47 | 0.43 | 0.48 | 0.59 | 0.55 | 0.48 | 0.39 | 0.38 | 0.47 | 0.51 | 0.48 |
| Width bodice WB | 0.54 | 0.43 | 0.49 | 0.42 | 0.64 | 0.67 | 0.84 | 0.6 | 0.58 | 0.64 | 0.72 | 0.72 | 0.61 |
| **Area of dress = (LS * 2)* WS + (DB * 2) * WB** | | | | | | | | | | | | | **1.18** |

**Report 4.15: Copy of page 1 of 90 pages from 'Amarna Diameters' spreadsheet. Analysis using source data from the database in Kemp 2001 Amarna Project: Workmens' Village Textiles. Diameter database of textiles found at Amarna. Accessed 21st April 2008. from http://www.amarnaproject.com/pages/recent_projects/material_culture/workmans.shtml**

| Square | Level/Unit | No | Year | Grid | Dia | Count |
|---|---|---|---|---|---|---|
| F25 (LWS 5) | MnSt | 1 | 79 | 4 | 1 | 1 |
| F25 (LWS 5) | MnSt | 2 | 79 | 4 | 1 | 1 |
| F25 (LWS 5) | MnSt | 3 | 79 | 4 | 1 | 1 |
| F25 (LWS 5) | MnSt | 4 | 79 | 4 | 1 | 1 |
| F25 (LWS 5) | MnSt | 5 | 79 | 4 | 1 | 1 |
| F25 (LWS 5) | MnSt | 6 | 79 | 4 | 1 | 1 |
| F25 (LWS 5) | MnSt | 7 | 79 | 4 | 1 | 1 |
| F25 (LWS 5) | MnSt | 8 | 79 | 4 | 1 | 1 |
| F25 (LWS 5) | MnSt | 9 | 79 | 4 | 1 | 1 |
| F25 (LWS 5) | MnSt | 10 | 79 | 4 | 1 | 1 |
| F25 (LWS 5) | MnSt | 11 | 79 | 4 | 1 | 1 |
| F25 (LWS 5) | MnSt | 12 | 79 | 4 | 1 | 1 |
| F25 (LWS 5) | MnSt | 13 | 79 | 4 | 1 | 1 |
| F25 (LWS 5) | MnSt | 14 | 79 | 4 | 1 | 1 |
| F25 (LWS 5) | MnSt | 15 | 79 | 4 | 1 | 1 |
| F25 (LWS 5) | MnSt | 16 | 79 | 4 | 1 | 1 |
| F25 (LWS 5) | MnSt | 17 | 79 | 4 | 1 | 1 |
| F25 (LWS 5) | MnSt | 18 | 79 | 4 | 1 | 1 |
| F25 (LWS 5) | MnSt | 19 | 79 | 4 | 1 | 1 |
| F25 (LWS 5) | MnSt | 20 | 79 | 4 | 1 | 1 |
| F25 (LWS 5) | MnSt | 21 | 79 | 4 | 1 | 1 |
| F25 (LWS 5) | MnSt | 22 | 79 | 4 | 1 | 1 |
| F25 (LWS 5) | MnSt | 23 | 79 | 4 | 1 | 1 |
| F25 (LWS 5) | MnSt | 24 | 79 | 4 | 1 | 1 |
| F25 (LWS 5) | MnSt | 25 | 79 | 4 | 1 | 1 |
| F25 (LWS 5) | MnSt | 26 | 79 | 4 | 1 | 1 |
| F25 (LWS 5) | MnSt | 27 | 79 | 4 | 1 | 1 |
| F25 (LWS 5) | MnSt | 28 | 79 | 4 | 1 | 1 |
| F25 (LWS 5) | MnSt | 29 | 79 | 4 | 1 | 1 |
| F25 (LWS 5) | MnSt | 30 | 79 | 4 | 1 | 1 |
| F25 (LWS 5) | MnSt | 31 | 79 | 4 | 1 | 1 |
| F25 (LWS 5) | MnSt | 32 | 79 | 4 | 1 | 1 |
| F25 (LWS 5) | MnSt | 33 | 79 | 4 | 1 | 1 |
| F25 (LWS 5) | MnSt | 34 | 79 | 4 | 1 | 1 |
| F25 (LWS 5) | MnSt | 35 | 79 | 4 | 1 | 1 |
| F25 (LWS 5) | MnSt | 36 | 79 | 4 | 1 | 1 |
| F25 (LWS 5) | MnSt | 37 | 79 | 4 | 1 | 1 |
| F25 (LWS 5) | MnSt | 38 | 79 | 4 | 1 | 1 |
| F25 (LWS 5) | MnSt | 39 | 79 | 4 | 1 | 1 |
| F25 (LWS 5) | MnSt | 40 | 79 | 4 | 1 | 1 |
| F25 (LWS 5) | MnSt | 41 | 79 | 4 | 1 | 1 |
| F25 (LWS 5) | MnSt | 42 | 79 | 4 | 1 | 1 |
| F25 (LWS 5) | MnSt | 43 | 79 | 4 | 1 | 1 |
| F25 (LWS 5) | MnSt | 44 | 79 | 4 | 1 | 1 |
| F25 (LWS 5) | MnSt | 45 | 79 | 4 | 1 | 1 |
| F25 (LWS 5) | MnSt | 46 | 79 | 4 | 1 | 1 |
| F25 (LWS 5) | MnSt | 47 | 79 | 4 | 1 | 1 |
| F25 (LWS 5) | MnSt | 48 | 79 | 4 | 1 | 1 |

| | Yarn diam. ranges mm | Sample count n=3385 | % |
|---|---|---|---|
| 1 | 0-0.2 | 503 | 14.9 |
| 2 | 0.2-0.3 | 2,407 | 71 |
| 3 | 0.4-0.6 | 435 | 12.9 |
| 4 | 0.6-0.9 | 34 | 1 |
| 5 | GT 0.9 | 6 | 0.2 |
| | Totals | 3,385 | 100 |

↓ **Page 1 of 90 pages from Amarna diameters spreadsheet available from the author via post-graduate office, inter-library loans, Swansea Univesity**

**Report 4.16: Copy of page 1 of 52 pages from 'Warp and Weft' spreadsheet. Analysis using source data from the database in Kemp 2001 Amarna Project: Workmens' Village Textiles. Warp and weft database of textiles found at Amarna. Accessed 21st April 2008. from http://www.amarnaproject.com/pages/recent_projects/material_culture/workmans.shtml**

| Diameter mm | Smple count | % | Warp | | Weft | |
|---|---|---|---|---|---|---|
| | | | Average | Median | Average | Median |
| LT 0.2 | 461 | 17.9 | 29.4 | 29 | 16.9 | 16 |
| 0.2-0.3 | 1760 | 68.2 | 22.6 | 22 | 12.3 | 12 |
| 0.4-0.6 | 346 | 13.4 | 17.6 | 18 | 9.5 | 9 |
| 0.6-0.9 | 15 | 0.6 | 10.1 | 8 | 8.1 | 7 |
| GT 0.9 | | | | | | |
| | **2582** | | | | | |

**Analysis using source data from the database in Kemp 2001 Amarna Project: Workmens' Village Textiles. Warp and weft database of Amarna textiles. Accessed 21st April 2008. from http://www.amarnaproject.com/pages/recent_projects/material_culture/workmans.shtml**

| | | | | | | | | | Count | WP 2 | | n | | Wft 2 | n |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| O15/16/P16 | cleaning | 3042 | 81 | 4 | 1 | 5 | 4 | 1 | 1 | 5 | 1 0-10 | 2 | 1 0-7 | 4 | 3 |
| M11 | [264] | 3602 | 83 | 4 | 1 | 9 | 4 | 1 | 1 | 9 | 2 11-20 | 283 | 2 8-14 | 4 | 304 |
| O15 | 7 | 2980 | 81 | 4 | 1 | 11 | 12 | 1 | 1 | 11 | 3 21-30 | 22 | 3 15-21 | 7 | 289 |
| M10 | 3 | 2446 | 81 | 4 | 1 | 12 | 11 | 1 | 1 | 12 | 4 31-40 | 0 | 4 22-28 | 8 | 9 |
| O15/16/P16 | cleaning | 3041 | 81 | 4 | 1 | 12 | 12 | 1 | 1 | 12 | 5 41-50 | 0 | 5 29-35 | 8 | 0 |
| L17 | dump | 640 | 80 | 4 | 1 | 12 | 18 | 1 | 1 | 12 | 6 51-60 | 0 | | 8 | |
| O15 | 7 | 2977 | 81 | 4 | 1 | 13 | 12 | 1 | 1 | 13 | 7 60-70 | 1 | | 9 | |
| M10 | [75] | 3331 | 82 | 4 | 1 | 13 | 13 | 1 | 1 | 13 | | **308** | | 9 | **605** |
| M16 | 3 | 706 | 80 | 4 | 1 | 14 | 9 | 1 | 1 | 14 | | | | 9 | |
| L18 | 7 | 2142 | 81 | 4 | 1 | 15 | 8 | 1 | 1 | 15 | | | | 9 | |
| M16 | 1 | 665 | 80 | 4 | 1 | 15 | 10 | 1 | 1 | 15 | | | | 9 | |
| M9 | 8 | 2300 | 81 | 4 | 1 | 15 | 10 | 1 | 1 | 15 | | | | 9 | |
| M9 | 8 | 2304 | 81 | 4 | 1 | 15 | 10 | 1 | 1 | 15 | | | | 9 | |
| N15 | 1 | 2586 | 81 | 4 | 1 | 15 | 10 | 1 | 1 | 15 | | | | 9 | |
| N16 | 1 | 966 | 80 | 4 | 1 | 15 | 12 | 1 | 1 | 15 | | | | 9 | |
| N15 | 7 <3> | 2817 | 81 | 4 | 1 | 15 | 12 | 1 | 1 | 15 | | | | 9 | |
| | surface | 3196 | 81 | 4 | 1 | 15 | 12 | 1 | 1 | 15 | | | | 10 | |
| O15 | 7 | 2967 | 81 | 4 | 1 | 15 | 13 | 1 | 1 | 15 | | | | 10 | |
| | surface | 3187 | 81 | 4 | 1 | 15 | 13 | 1 | 1 | 15 | | | | 10 | |
| L16 | [14] | 3294 | 82 | 4 | 1 | 15 | 13 | 1 | 1 | 15 | | | | 10 | |
| M12 | [127] | 3486 | 82 | 4 | 1 | 15 | 16 | 1 | 1 | 15 | | | | 10 | |
| M9 | 8 | 2266 | 81 | 4 | 1 | 16 | 9 | 1 | 1 | 16 | | | | 10 | |
| M9 | 8 | 2306 | 81 | 4 | 1 | 16 | 9 | 1 | 1 | 16 | | | | 10 | |
| N15 | 1 | 2584 | 81 | 4 | 1 | 16 | 9 | 1 | 1 | 16 | | | | 10 | |
| M9 | 8 | 2264 | 81 | 4 | 1 | 16 | 10 | 1 | 1 | 16 | | | | 10 | |
| M9 | 1 | 2236 | 81 | 4 | 1 | 16 | 11 | 1 | 1 | 16 | | | | 10 | |
| M9 | 8 | 2296 | 81 | 4 | 1 | 16 | 12 | 1 | 1 | 16 | | | | 10 | |
| L18 | 7 | 2135 | 81 | 4 | 1 | 16 | 13 | 1 | 1 | 16 | | | | 10 | |
| M9 | 8 | 2295 | 81 | 4 | 1 | 16 | 13 | 1 | 1 | 16 | | | | 10 | |
| 016 | 2 | 3000 | 81 | 4 | 1 | 16 | 13 | 1 | 1 | 16 | | | | 10 | |
| M10 | 1/2 | 2341 | 81 | 4 | 1 | 16 | 15 | 1 | 1 | 16 | | | | 10 | |
| M16 | 3 | 714 | 80 | 4 | 1 | 16 | 18 | 1 | 1 | 16 | | | | 11 | |
| M9 | 8 | 2305 | 81 | 4 | 1 | 17 | 10 | 1 | 1 | 17 | | | | 11 | |
| M16 | 10 | 759 | 80 | 4 | 1 | 17 | 18 | 1 | 1 | 17 | | | | 11 | |
| Q15 | [599] | 3847 | 83 | 4 | 1 | 18 | 9 | 1 | 1 | 18 | | | | 11 | |
| M9 | 8 | 2248 | 81 | 4 | 1 | 18 | 11 | 1 | 1 | 18 | | | | 11 | |
| L17 | dump | 643 | 80 | 4 | 1 | 18 | 13 | 1 | 1 | 18 | | | | 11 | |

**Page 1 of 90 pages from 'Warp and Weft' spreadsheet available from the author via post-graduate office, inter-library loans, Swansea University**

# Shelter: Brick production

| Report 5.1: Manpower required to make 1000 mud bricks. Reference Fathy 1973: 200 | | | | |
|---|---|---|---|---|
| **Number of bricks made per day** | 3000 | | Number of workmen making bricks | 4 |
| Man-days/1000 bricks | 0.75 | | | |
| **Number of man-days required to produce 1000 bricks** | | | | |
| Volume of mud per 1000 mud bricks | 1.52 | $m^3$ | Fathy 1973: 198. Prorated from 1 m3 of soil + 0.333 m3 of sand + 45 lb (20.42 kg) of straw made 660 bricks. | |
| Volume of dry sand to make 1000 bricks | 0.5 | $m^3$ | | |
| Wt. of wet mud carried from river/1000 mud bricks | 4316.8 | kg | Saad 1984: 4. Experimental results show wet Nile Mud =2840 $kg/m^3$ and dry = 1270 $kg/m^3$. Sand respectively 1922 $kg/m^3$ and 1602 $kg/m^3$. | |
| Wt. of wet sand carried from river/1000 mud bricks | 961 | kg | | |
| Total weight carried | 5277.8 | kg | | |
| Maximum load carried by man | 5 | kg | http://www.nerc.ac.uk/about/work/policy/safety/documents/procedure_manualhandling.pdf | |
| Assume no. of trips/hr/man including dredging mud and that the brickworks was in close proximity to the river | 12 | | | |
| Assume in antiquity max. load carried by man | 7.5 | kg | | |
| Total man-hours | 58.6 | hrs | | |
| Assume 10 hr day | 5.86 | man-days | | |
| **Number of man-days required to transport straw required to produce 1000 bricks reference Fathy 1973: 198** | | | | |
| Weight of straw to make 660 bricks | 45 | lbs | Fathy 1973: 198. | |
| Weight of straw to make 660 bricks | 20.4 | kg | Weight kg of straw to produce 100 bricks | 4.68 |
| Weight of straw or chaff to make 1000 bricks | 30.9 | kg | | |
| Straw production in antiquity from report in spreadsheet AGCALC | 1,435 | kg/ha | | |
| Area of land required per 1000 bricks | 0.0215 | ha | Area of land (ha) required to produce straw to make 660 bricks | **0.0142** |
| No. of man-days binding, transporting, and unloading straw from Report 2.22A in AGCALC | 21.76 | man-days/ha | | |
| Man-days required to transport straw | 0.47 | man-days | | |
| Assume uplifted to cut straw into strips suitable for brick making | 1 | man-days | | |
| Stacking and putting mud bricks on edge per 1000 mud bricks | 0.5 | man-days | | |
| **Total man-days to make 1000 bricks equivalent in size to a modern Egyptian mud brick** | 8.1 | man-days/1000 bricks | Fathy 1973: 200. | |

| Report 5.1a: Brick making daily rate adjusted for the larger size of NK bricks | | Length m | Width m | Height m | Volume $m^3$ | Ratio |
|---|---|---|---|---|---|---|
| Size of modern Egyptian brick | Modern Egyptian brick | 0.24 | 0.12 | 0.08 | 0.002304 | |
| Size of New Kingdom brick | New Kingdom mud brick | 0.28 | 0.14 | 0.0864 | 0.00338688 | 1.47 |
| | 11.9 | man-days/1000 bricks | | | | |

# Population Growth

**Report 5.2: Population growth per year analysis**

Population growth/yr 0.037695 %

Population start of NK 1,250,000 Final population 2,200,013 Sample no. 1500

Rounded final NK population 2.2 million

Population growth year on year at the end of the NK 829

Rounded pop at start of NK 1.25

Growth in population in the NK 0.95

| Year | Pop | Year | Pop | Year | Pop | Year | Pop | Year | Pop | Year | Pop | Year | Pop | Year | Pop |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1,250,471 | 101 | 1,298,500 | 201 | 1,348,373 | 301 | 1,400,160 | 401 | 1,453,936 | 501 | 1,509,778 | 601 | 1,567,764 | 701 | 1,627,977 |
| 2 | 1,250,942 | 102 | 1,298,989 | 202 | 1,348,881 | 302 | 1,400,688 | 402 | 1,454,484 | 502 | 1,510,347 | 602 | 1,568,355 | 702 | 1,628,591 |
| 3 | 1,251,414 | 103 | 1,299,479 | 203 | 1,349,389 | 303 | 1,401,216 | 403 | 1,455,032 | 503 | 1,510,916 | 603 | 1,568,946 | 703 | 1,629,205 |
| 4 | 1,251,886 | 104 | 1,299,969 | 204 | 1,349,898 | 304 | 1,401,744 | 404 | 1,455,580 | 504 | 1,511,486 | 604 | 1,569,537 | 704 | 1,629,819 |
| 5 | 1,252,358 | 105 | 1,300,459 | 205 | 1,350,407 | 305 | 1,402,272 | 405 | 1,456,129 | 505 | 1,512,056 | 605 | 1,570,129 | 705 | 1,630,433 |
| 6 | 1,252,830 | 106 | 1,300,949 | 206 | 1,350,916 | 306 | 1,402,801 | 406 | 1,456,678 | 506 | 1,512,626 | 606 | 1,570,721 | 706 | 1,631,048 |
| 7 | 1,253,302 | 107 | 1,301,439 | 207 | 1,351,425 | 307 | 1,403,330 | 407 | 1,457,227 | 507 | 1,513,196 | 607 | 1,571,313 | 707 | 1,631,663 |
| 8 | 1,253,774 | 108 | 1,301,930 | 208 | 1,351,934 | 308 | 1,403,859 | 408 | 1,457,776 | 508 | 1,513,766 | 608 | 1,571,905 | 708 | 1,632,278 |
| 9 | 1,254,247 | 109 | 1,302,421 | 209 | 1,352,444 | 309 | 1,404,388 | 409 | 1,458,326 | 509 | 1,514,337 | 609 | 1,572,498 | 709 | 1,632,893 |
| 10 | 1,254,720 | 110 | 1,302,912 | 210 | 1,352,954 | 310 | 1,404,917 | 410 | 1,458,876 | 510 | 1,514,908 | 610 | 1,573,091 | 710 | 1,633,509 |
| 11 | 1,255,193 | 111 | 1,303,403 | 211 | 1,353,464 | 311 | 1,405,447 | 411 | 1,459,426 | 511 | 1,515,479 | 611 | 1,573,684 | 711 | 1,634,125 |
| 12 | 1,255,666 | 112 | 1,303,894 | 212 | 1,353,974 | 312 | 1,405,977 | 412 | 1,459,976 | 512 | 1,516,050 | 612 | 1,574,277 | 712 | 1,634,741 |
| 13 | 1,256,139 | 113 | 1,304,386 | 213 | 1,354,484 | 313 | 1,406,507 | 413 | 1,460,526 | 513 | 1,516,621 | 613 | 1,574,870 | 713 | 1,635,357 |
| 14 | 1,256,613 | 114 | 1,304,878 | 214 | 1,354,995 | 314 | 1,407,037 | 414 | 1,461,077 | 514 | 1,517,193 | 614 | 1,575,464 | 714 | 1,635,973 |
| 15 | 1,257,087 | 115 | 1,305,370 | 215 | 1,355,506 | 315 | 1,407,567 | 415 | 1,461,628 | 515 | 1,517,765 | 615 | 1,576,058 | 715 | 1,636,590 |
| 16 | 1,257,561 | 116 | 1,305,862 | 216 | 1,356,017 | 316 | 1,408,098 | 416 | 1,462,179 | 516 | 1,518,337 | 616 | 1,576,652 | 716 | 1,637,207 |
| 17 | 1,258,035 | 117 | 1,306,354 | 217 | 1,356,528 | 317 | 1,408,629 | 417 | 1,462,730 | 517 | 1,518,909 | 617 | 1,577,246 | 717 | 1,637,824 |
| 18 | 1,258,509 | 118 | 1,306,846 | 218 | 1,357,039 | 318 | 1,409,160 | 418 | 1,463,281 | 518 | 1,519,482 | 618 | 1,577,841 | 718 | 1,638,441 |
| 19 | 1,258,983 | 119 | 1,307,339 | 219 | 1,357,551 | 319 | 1,409,691 | 419 | 1,463,833 | 519 | 1,520,055 | 619 | 1,578,436 | 719 | 1,639,059 |
| 20 | 1,259,458 | 120 | 1,307,832 | 220 | 1,358,063 | 320 | 1,410,222 | 420 | 1,464,385 | 520 | 1,520,628 | 620 | 1,579,031 | 720 | 1,639,677 |
| 21 | 1,259,933 | 121 | 1,308,325 | 221 | 1,358,575 | 321 | 1,410,754 | 421 | 1,464,937 | 521 | 1,521,201 | 621 | 1,579,626 | 721 | 1,640,295 |
| 22 | 1,260,408 | 122 | 1,308,818 | 222 | 1,359,087 | 322 | 1,411,286 | 422 | 1,465,489 | 522 | 1,521,774 | 622 | 1,580,221 | 722 | 1,640,913 |
| 23 | 1,260,883 | 123 | 1,309,311 | 223 | 1,359,599 | 323 | 1,411,818 | 423 | 1,466,041 | 523 | 1,522,348 | 623 | 1,580,817 | 723 | 1,641,532 |

**Data continued and available in digital form from the author on request**

**SHELTER (Domestic housing growth)**

**Report 5.3. Number of bricks and manpower required for three main types of Amarna domestic housing**

| | | |
|---|---|---|
| Volume of typical MK/NK mud brick = | 0.00338688 | $m^3$ |
| Tot man-days to make 1000 standard NK bricks = | **11.9** | man-days |
| Assume number of days worked per year | **308** | days |

Tietze 1985: 78, Abb 15.

| | |
|---|---|
| **Number of NK standard bricks laid per day from Report 5.7** | **738** |

| | | | |
|---|---|---|---|
| Man-days to mix mud mortar per brick layer | 0.25 | Total = | Ratio |
| Man-days to handle mortar | 2.5 | 3.75 | 4.75 |
| Man-days supplying bricks from the stacks | 1 | | |

| **Uplifts for fiting roofs, floors, scafolding, lifting bricks** | **%** |
|---|---|
| Working classes | 5 |
| Professional middle classes | 10 |
| City elite | 35 |

| **Uplift for scafolding, lifting bricks & mortar** | |
|---|---|
| **Height of structure** | **Uplift ratio** |
| 0 to 6 m | 1.5 |
| 7 to 11 m | 3 |

**Type 1c house**

| | | |
|---|---|---|
| Wall thickness of inner walls of type 1c house at Amarna inner walls | 0.1575 | m |
| Wall thickness of outer walls of type 1c house at Amarna inner walls | 0.1575 | m |
| Total length of inner walls | 32.4 | m |
| Height of inner walls | 3.5 | m |
| Total length of outer walls/out houses | 74.6 | m |
| Height of outer walls | 2.5 | m |
| Surface area of ancillary brickwork on roof | 38.28 | $m^2$ |
| Volume of inner wall | 17.9 | $m^3$ |
| Volume of out houses walls and single thick mud brick walls | 29.4 | $m^3$ |
| Volume of ancillary brickwork on the roof | 6 | $m^3$ |
| Total volume of mud brick walls | 53.3 | $m^3$ |
| Number of bricks required | 15,737 | |
| Man-days to make bricks alone | 188 | man-days |
| Man-days to lay bricks + mortar mixers and carriers | 160 | man-days |
| Man-days to make and lay bricks | 348 | man-days |
| **Man-years to build house uplifted for roof, fittings, foundations etc** | **1.1** | **man-yrs** |

**Type 2d house**

| | | |
|---|---|---|
| Wall thickness of inner walls of type 2d house at Amarna inner walls | 0.34 | m |
| Wall thickness of outer walls of type 2d house at Amarna inner walls | 0.1575 | m |
| Tot. length of inner walls + outer building + butressed encl're wall 2 bricks thick | 138.2 | m |
| Height of inner walls | 3 | m |
| Total length of outer walls/out houses | 80.8 | m |
| Height of outer walls Kemp 2000: 296. | 3 | m |
| Surface area of ancillary brickwork on roof | 40.14 | $m^2$ |
| Volume of inner wall | 141 | $m^3$ |
| Volume of out houses walls and single thick mud brick walls | 38.2 | $m^3$ |
| Volume of ancillary brickwork on the roof | 6.3 | $m^3$ |
| Total volume of mud brick walls | 185.5 | $m^3$ |
| Number of bricks required | 54,770 | |
| Man-days to make bricks alone | 652 | man-days |
| Man-days to lay bricks | 582 | man-days |
| **Man-years to make and lay bricks** | **4.1** | **man-yrs** |

**Type 1a house**

| | | |
|---|---|---|
| Total length of walls | 26.2 | m |
| Wall thickness | 0.1575 | m |
| Height of wall | 2.5 | m |
| Total volume of mud brick walls | 10.4 | $m^3$ |
| Number of bricks required | 3,071 | |
| Man-days to make bricks | 37 | man-days |
| Man-days to lay bricks | 32 | man-days |
| Man-days to make and lay bricks | 69 | man-days |
| Man-years to build house uplifted for roof, fittings, foundations etc | 0.2 | man-yrs |

| **House designs** | **1a** | **1b** | **1c** | **2d** | **3e** |
|---|---|---|---|---|---|
| No. of bricks required | 3,071 | 3,809 | 15,737 | 54,770 | 230,478 |
| Man-days to make bricks | 37 | 45 | 188 | 652 | 2,743 |
| Man-days to build house | 32 | 50 | 160 | 582 | 3,004 |
| Total man-days | 69 | 95 | 348 | 1234 | 5747 |
| **Total man-years** | **0.2** | **0.3** | **1.1** | **4.1** | **25.2** |

**Type 3e Palace style**

| | | |
|---|---|---|
| Tot. thickness of outer palace walls | 0.8 | m |
| Tot. thickness of internal walls of palace excluding central high status room | 0.4725 | m |
| Wall thickness of high status room | 0.4725 | m |
| Wall thickness of outhouses | 0.1575 | m |
| Thickness of enclosure wall | 0.4 | m |
| Thickness of ancilliary buildings on the roof | 0.3 | m |
| | | |
| Tot. length of outer palace walls | 84.3 | m |
| Tot. length of internals excluding central high status room | 71.1 | m |
| Total length of high status room | 27.4 | m |
| Total length of the walls of the out houses | 105.7 | m |
| Total length of butressed outer walls | 144 | m |
| Total length of all walls | 432.5 | m |
| Height of outer palace walls | 4 | m |
| Height of palace internal walls excluding central high status room | 4 | m |
| Height of high status room | 5.4 | m |
| Height of out house walls | 2.9 | m |
| Height of butressed outer walls | 4 | m |
| | | |
| Area of ancilliary fixtures on the roofs | 92.25 | $m^2$ |
| | | |
| Volume of outer palace walls | 269.8 | $m^3$ |
| Volume of palace internal walls excluding central high status room | 134.4 | $m^3$ |
| Volume of high status room | 70 | $m^3$ |
| Volume of out house walls | 48.3 | $m^3$ |
| Volume of butressed outer walls | 230.4 | $m^3$ |
| Volume of ancillary rooms on the roofs | 27.7 | $m^3$ |
| Total volume of mud brick walls | **780.6** | $m^3$ |
| Number of bricks required | **230,478** | |
| Man-days to make bricks alone | 2,743 | man-days |
| Man-days to lay bricks | 3,004 | man-days |
| Man-days to make and lay bricks | **5,747** | man-days |
| Man-years to build house uplifted for roof, fittings, foundations etc | **25.2** | man-years |

Tietze 1985: 78, Abb 15.

**Type 1b house**

| | | |
|---|---|---|
| Total length of walls | 32.6 | m |
| Wall thickness | 0.1575 | m |
| Height of wall | 2.5 | m |
| Total volume of mud brick walls | 12.9 | $m^3$ |
| Number of bricks required | 3,809 | |
| Man-days to make bricks | 45 | man-days |
| Man-days to lay bricks | 50 | man-days |
| Man-days to make and lay bricks | 95 | man-days |
| Man-years to build house uplifted for roof, fittings, foundations etc | **0.3** | man-yrs |

## Report 5.4. Total housing growth required per year for New Kingdom Egypt

| Demographic split of housing at Amarna | | Tietze 1985: 83-84. |
|---|---|---|
| Working classes | 56.5 | |
| Professional middle classes | 35.5 | |
| City elite | 8 | |
| | 100 | |

**Max. Population growth per year**

| | |
|---|---|
| Length of New Kingdom | 1,500 |
| Population growth at beginning of NK | 1,250,000 |
| If the population of the Nile valley at the end of the New Kingdom = | 2,200,000 |
| Growth | 950,000 |
| Calculated growth from Report 5.2 | 0.037695 |
| Min growth rate/annum | 614 |
| **Max growth rate** | **829** |

## Report 5.4a Prorating growth in population per year to ratio of social group size

| | |
|---|---|
| Agrarian population + 56.5% of Urban cities, towns etc | 795 |
| Professional middle classes | 28 |
| City elite | 6 |
| **Maximum population growth per year** | **0** |

**Annual house requirement**

**Assume family size/nuclear family =** 6 Kemp 1991: 157.

| | |
|---|---|
| Agrarian population + 56.5% of Urban cities, towns etc | 133 |
| Professional middle classes | 5 |
| City elite | 1 |
| **Total housing growth per year** | **#REF!** |

**Annual requirement for the total population of 2.2 million**

| | |
|---|---|
| Total New Kingdom houses required assuming a compound population growth of | 0.037695 |
| Agrarian/cloth/urban working class | 0 |
| Professional middle classes | 0 |
| City elite | 0 |
| **Total increase in population per year** | **#REF!** |

## Report 5.4b: Allocation of NK population in urban and non urban environments

| | |
|---|---|
| From AGCALC Report 2.31 the agrarian population/100,000 population sample | 37,205 |
| Domestic housing | 107 |
| Domestic pottery | 66 |
| From CLOTHCALC Reports 3.12i-3.12h, cloth workers/100,000 population sample | 14,659 |
| From BRONZECALC Report 5. bronze workers/100,000 population sample | 14,133 |
| No. of unproductive population under 6 and 55+ years old/100,000 population (AGCALC) | 30,860 |
| Elite | 2,970 |
| Total | 100,000 |

| | |
|---|---|
| Agrarian + cloth + added value + others | 69,140 |
| Prorating unproductive population | 21,337 |
| Population living outside of urban areas | 90,477 |
| Population living within urban areas | 9,523 |
| Total | 100,000 |
| Population living outside of urban environments | 1,990,494 |

| | |
|---|---|
| **Percentage living in urban areas** | **9.5** |
| **Percentage living in non-urban areas** | **90.5** |

| Total population collated by socio-economic groups | | % |
|---|---|---|
| Non-urban agrarian, cloth, bronze workers | 1,990,494 | 9.5 |
| Urban workers, middle professional classes, and the elite | 209,506 | 90.5 |
| **Population by socio-economic group** | **2,200,000** | **100** |

## Report 5.4c: Total population collated by socio-economic group

| Total population collated by socio-economic groups | | % |
|---|---|---|
| Non-urban agrarian, cloth, bronze workers+56.5% of Urban population | 2,108,865 | 95.9 |
| Middle professional classes | 74,375 | 3.4 |
| Urban elite | 16,760 | 0.7 |
| **Population by socio-economic group** | **2,200,000** | **100** |

## Report 5.4d: Total annual growth in population and housing collated by socio-economic groups

| Total annual growth in population and housing collated by socio-economic groups | Population growth | Housing requirement |
|---|---|---|
| Non-urban population + 56.5% of Urban cities, towns etc | 795 | 133 |
| Professional middle classes | 28 | 5 |
| City elite | 6 | 1 |
| **Total** | **829** | **139** |

**Report 5.5a: Percentage split of non-urban classes by designs 1a, 1b, 1c, and 2c**

| Type | % | Houses | Bricks |
|---|---|---|---|
| 1a | 65 | 86 | 264,078 |
| 1b | 20 | 27 | 102,839 |
| 1c | 10 | 13 | 204,584 |
| 2c | 5 | 7 | 383,392 |
| **Total** | **100** | **133** | **954,893** |

**Report 5.5b: Number of bricks and manpower required to make them and build the houses**

| Total number of bricks required for annual housing growth | |
|---|---|
| Non-urban population + 56.5% of Urban cities, towns etc | 954,893 |
| Professional middle classes | 0 |
| City elite | 0 |
| **Total** | **954,893** |

**Report 5.5c: Man-power required to build sufficient houses to meet annual demand uplifted for roof, fittings, foundations etc**

| Manpower requirents | Making bricks | Building | Total |
|---|---|---|---|
| Agrarian population + 56.5% of Urban cities, towns etc | 11,363 | 9,680 | 21,043 |
| Professional middle classes | 0 | 0 | 0 |
| City elite | 0 | 0 | 0 |
| Total man-days | 11,363 | 9,680 | 21,043 |
| **Total man-years** | **37** | **31** | **68** |

**Report 5.6: Domestic housing for the whole of Amarna.**

| | | |
|---|---|---|
| Kemp's analysis of population minimum | 20,000 | Kemp 1981: 81-97. |
| Kemp states that the nos. above are probably understated. Max taken for this analysis. | 30,000 | Kemp 1991: 306. |
| Janssen's population estimate | 50,000 | Janssen 1983: 273-288. |

| | |
|---|---|
| **Assume family size/nuclear family** | 6 |
| Working days/yr | 0 |

**Percentage demographic split of housing at Amarna**

| | % |
|---|---|
| **Working classes** | 56.5 |
| **Professional middle classes** | 35.5 |
| **City elite** | 8 |
| | **100** |

**No. of houses collated by socio-economic group**

| | **Kemp** | **Janssen** | Kemp 2008b: 34 |
|---|---|---|---|
| **Working classes** | 2825 | 4709 | 1718 |
| **Professional middle classes** | 1775 | 2959 | 1079 |
| **City elite** | 400 | 667 | 243 |
| | **5,000** | **8,335** | **3,040** |

**Percentage demographic population at Amarna**

| | **Tietze %** | **Kemp** | **Janssen** |
|---|---|---|---|
| **Working classes** | 56.5 | 16950 | 28250 |
| **Professional middle classes** | 35.5 | 10650 | 17750 |
| **City elite** | 8 | 2400 | 4000 |
| | **100** | **30,000** | **50,000** |

**Report 5.7: Based on Kemp's esimation of 30,000 max population and Janssen's 50,000 population and family size of 6**

**No. of bricks required collated by socio-economic group**

| **Number of mud bricks required** | **Kemp** | **Janssen** |
|---|---|---|
| **Working classes** | 44,457,583 | 74,106,464 |
| **Professional middle classes** | 97,217,055 | 162,064,939 |
| **City elite** | 92,191,043 | 153,728,564 |
| | **233,865,681** | **389,899,967** |

| **Bricks required per house** | |
|---|---|
| **Working classes** | 15,737 |
| **Professional middle classes** | 54,770 |
| **City elite** | 230,478 |

**Total man-days to make bricks collated by socio-economic group**

| **No. of man-days** | **Kemp** | **Janssen** |
|---|---|---|
| Working classes | 529,046 | 881,867 |
| Professional middle classes | 1,156,883 | 1,928,573 |
| City elite | 1,097,074 | 1,829,370 |
| **Total** | **2,783,003** | **4,639,810** |

**Total man-days to build house uplifted for roof, fittings, foundations etc**

| **No. of man-days** | **Kemp** | **Janssen** |
|---|---|---|
| Working classes | 450,676 | 751,232 |
| Professional middle classes | 1,032,438 | 1,721,117 |
| City elite | 1,201,576 | 2,003,627 |
| **Total** | **2,684,690** | **4,475,976** |

**No. of man-years to make bricks collated by socio-economic group**

| **No. of man-years** | **Kemp** | **Janssen** |
|---|---|---|
| Working classes | 1,718 | 2,863 |
| Professional middle classes | 3,756 | 6,262 |
| City elite | 3,562 | 5,940 |
| **Total** | **9,036** | **15,064** |

**No. of man-years to build houses collated by socio-economic group**

| No. of man-years | Kemp | Janssen |
|---|---|---|
| Working classes | 1,463 | 2,439 |
| Professional middle classes | 3,352 | 5,588 |
| City elite | 3,901 | 6,505 |
| **Total** | **8,717** | **14,532** |

Romer's analysis of the Great Pyramid — Romer 2008

| | |
|---|---|
| 1 | 24,136 |
| 2 | 13,250 |
| 3 | 10,750 |
| 4 | 10,417 |
| 5 | 8,375 |
| 6 | 7,333 |
| 7 | 6,458 |
| 8 | 6,129 |
| 9 | 5,625 |
| 10 | 5,375 |
| 11 | 4,792 |
| 12 | 4,060 |
| 13 | 3,750 |
| 14 | 3,333 |
| | 113,783 |
| | 114,000 |

**No. of man-years to make bricks + build houses collated by socio-economic group**

| No. of man-years | Kemp | Janssen |
|---|---|---|
| Working classes | 3,181 | 5,302 |
| Professional middle classes | 7,108 | 11,850 |
| City elite | 7,463 | 12,445 |
| Total | 17,752 | 29,597 |
| **Rounded total** | **18,000** | **30,000** |

**Report 5.7: Based on Kemp's esimation of 30,000 max population and Janssen's 50,000 population and family size of 6**

**No. of bricks required collated by socio-economic group**

| No. of mud bricks required | Kemp |
|---|---|
| **Working classes** | 27,036,506 |
| **Professional middle classes** | 59,097,016 |
| **City elite** | 56,006,059 |
| | **142,139,581** |

| Bricks required per house | |
|---|---|
| **Working classes** | 15,737 |
| **Professional middle classes** | 54,770 |
| **City elite** | 230,478 |

**Total man-days to make bricks collated by socio-economic group**

| No. of man-days | Kemp |
|---|---|
| Working classes | 321,735 |
| Professional middle classes | 703,255 |
| City elite | 666,473 |
| **Total** | **1,691,463** |

**Total man-days to build house uplifted for roof, fittings, foundations etc**

| No. of man-days | Kemp |
|---|---|
| Working classes | 274,075 |
| Professional middle classes | 627,606 |
| City elite | 729,958 |
| **Total** | **1,631,639** |

**No. of man-years to make bricks collated by socio-economic group**

| No. of man-years | Kemp |
|---|---|
| Working classes | 1,045 |
| Professional middle classes | 2,283 |
| City elite | 2,164 |
| **Total** | **5,492** |

**No. of man-years to build houses collated by socio-economic group**

| No. of man-years | Kemp |
|---|---|
| Working classes | 890 |
| Professional middle classes | 2,038 |
| City elite | 2,370 |
| **Total** | **5,298** |

**No. of man-years to make bricks + build houses collated by socio-economic group**

| No. of man-years | Kemp |
|---|---|
| Working classes | 1,934 |
| Professional middle classes | 4,321 |
| City elite | 4,534 |
| **Total** | **10,789** |
| **Rounded total** | **11,000** |

1

# SHELTER (State building projects)

**Report 5.7d: Size of bricks known from the archaeological record**

Assuming no. of available days/year available for work 308 days

| Size of bricks | Length m | Width m | Height m | Volume $m^3$ | Report 5.7e: Man-days to make 1000 bricks | No. of bricks laid per day | Source |
|---|---|---|---|---|---|---|---|
| Modern Egyptian mud brick made with the process analysed in Report 5.1 | 0.24 | 0.12 | 0.08 | 0.002304 | 8.1 | 1085 | Fathy 1973: 97. |
| Middle Kingdom/New Kingdom brick | 0.28 | 0.14 | 0.0864 | 0.00338688 | 11.9 | 738 | Kemp 2000: 87. |
| Middle Kingdom/New Kingdom fortress at Buhen | 0.37 | 0.18 | 0.12 | 0.007992 | 28.1 | 313 | Emery et al 1979: 39. |
| Mesopotamian brick size used to build palace at Tell al Rimah Ziggurat | 0.3 | 0.3 | 0.12 | 0.0108 | 38 | 231 | Estimated from Oates 1990: 395, figure 5. |
| Mesopotamian brick size used for administrative buidings | 0.2 | 0.085 | 0.08 | 0.00136 | 4.8 | 1838 | |
| | 0.23 | 0.09 | 0.065 | 0.0013455 | 4.7 | 1858 | |
| Ramesseum granary walls | 0.4 | 0.12 | 0.13 | 0.00624 | 21.9 | 401 | Spencer 1979: 86. |
| Ramesseum granary vault | 0.35 | 0.21 | 0.065 | 0.0047775 | 16.8 | 523 | |

| | | |
|---|---|---|
| % ratio of the vol. of a Buhen to a standard MK/NK mud brick | 236 | % |
| Volume of mud brick wall built by modern Egyptian brick-layer | 2.5 | $m^3$ |

**Report 5.7f**

| | Scafolding/lifting bricks and mortar: Height of structure | | Uplift ratio | |
|---|---|---|---|---|
| | Walls under 1.25 m in height | | 0 | Based on ethnographic scafolding evidence Fathy 1973:208 |
| | Walls 1.25-2.5 | | 1.5 | |
| | Walls between 2.5-6 m in ht | | 2 | |
| | Walls between 6-11 m in ht | | 3 | |
| Man-days to mix mud mortar per brick layer | 0.25 | Total = | Ratio | |
| Man-days to handle mortar | 2.5 | 3.75 | 5 | |
| Man-days supplying bricks from the stacks | 1 | | | |
| | Rounded | 4 | 5 | |

**Report 5.8: Manpower requirements for four types of state buildings**

**Report 5.8a: Palace of Naram-Sin, Tell Brak, Northern Mesopotamia.** Oates 1990: 390.

| | | |
|---|---|---|
| Number of bricks | 810,000 | man-days |
| Total man-days required to make bricks | 30,780 | man-years |
| Total man-years required to make bricks | 100 | man-years |
| Man-years to lay bricks + mortar mixers and carriers + ht uplift | 163 | man-years |
| **Total man-years to make bricks & build the structure including ht uplift** | **263** | **man-years** |

**Report 5.8b: Enclosure wall built for the Middle Kindom town of Lahun.** Szpakowska 2008: 14.

| | | | |
|---|---|---|---|
| Height of wall | 6.5 | m | |
| Width of wall | 3 | m | |
| Boundary length | 1,500 | m | Uphill 1988: 27-28, figure 12. |
| Volume of wall | 20,865.0 | $m^3$ | |
| Number of bricks | 6,160,537 | | |
| Total man-days required to make bricks | 73,310 | man-days | |
| Total man-years required to make bricks | 239 | man-years | |
| Total man-years to build the structure including height uplift | 194 | man-years | |
| **Total man-years to make bricks and build the structure** | **433** | **man-years** | |

**Report 5.8c: Enclosure wall built for the town of Sesebi (between the second and third cataracts) by Akhenaten.**

| | | | |
|---|---|---|---|
| **Wall** | | | Uphill 1988: 36-37, figure 16. |
| Height of wall | 6.5 | m | |
| Width of wall | 4.6 | m | |
| Boundary length | 1,070 | m | |
| Volume of wall | 31,993 | $m^3$ | |
| **Buttresses** | | | |
| Total number | 56 | | |
| Height | 6.5 | m | |
| Width | 3 | m | |
| Projection from wall | 3 | m | |
| Volume of buttresses | 3,038 | $m^3$ | |
| Total number of bricks required | 10,343,292 | | |
| Total man-days required to make bricks | 123,086 | man-days | |
| Total man-years required to make bricks | 400 | man-years | |
| Total man-years to build the structure including height uplift | 325 | man-years | |
| Total man-years to make bricks and build the structure | **725** | **man-years** | |

**Report 5.8d: Granary built for the Nubian fortress of Mirgissa**

Assume bricks equivalent size to Buhen

| | | |
|---|---|---|
| Height of wall | 6.5 | m |
| Width of wall | 4.6 | m |
| Boundary length | 1,070 | m |
| Volume of wall | 31,993 | $m^3$ |
| Tot. no. of bricks required | 9,446,157 | |
| Total man-days required to make bricks | 265,438 | man-days |
| Total man-years required to make bricks | 862 | man-years |
| Total man-years to build the structure including height uplift | 1,397 | man-years |
| Total man-years to make bricks and build the structure | **2,259** | **man-years** |

**Report 5.8e: The Middle Kingdom fortress at Buhen**

| | | | | |
|---|---|---|---|---|
| Height of main defensive wall | 11 | m | Emery et al 1979: 38-41. | |
| Tot. no. of bricks required | 13,318,057 | | | |
| Total man-days required to make bricks | 374,238 | man-days | Daily rate of brick laying | 313 |
| Total man-years required to make bricks | 1,216 | man-years | | |
| Total man-years to build the structure including height uplift | 1,969 | man-years | | |
| Total man-years to make bricks and build the structure | **3,185** | man-years | | |

**Report 5.8f: The Ramessum granary at Thebes**

| **Ramesseum external walls** | | |
|---|---|---|
| Thickness enclosure walls 1 | 3.1 | m |
| Thickness main walls 2 | 2.2 | m |
| Length enclosure walls 1 | 689 | m |
| Length main walls 2 | 268 | m |
| Ht enclosure walls 1 | 6.7 | m |
| Ht main walls 2 | 5.2 | m |
| Combined volume of enclosure + walls 2 | 17,376 | $m^3$ |
| No. of bricks for main walls | 2,784,615 | |
| Man-days to make bricks of main walls | 60,983 | man-days |
| Man-years to make bricks of main walls | 198 | man-years |
| Man-years to build main walls | 161 | man-years |
| Tot man-years to make bricks and build external+internal vertical walls | **359** | man-years |

| | |
|---|---|
| Brick laying team size | 15 |
| Daily rate of brick laying | 401 |

| **Ranesseum granary compartments** | | |
|---|---|---|
| Width of compartments inside span | 3.8 | m |
| Width of compartments inside span + one wall hickness | 5.7 | m |

| Compartment section | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| No. of compartments | 15 | 15 | 6 | 6 | 13 | 9 | 17 | 13 |
| Length of compartments m | 30 | 30 | 54 | 54 | 28.5 | 28.5 | 19 | 12 |
| Thickness m | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 |
| Ht of vert'l wall in compartment, 22 bricks high with brick ht 0.0864 m | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 |
| Volume of vertical walls | 1038 | 1038 | 668 | 668 | 846 | 564 | 752 | 356 |
| Length of span 2.3 times height of vertical walls | 4.37 | 4.37 | 4.37 | 4.37 | 4.37 | 4.37 | 4.37 | 4.37 |
| Volume of spans $m^3$ | 2556.5 | 2556.5 | 1840.6 | 1840.6 | 2104.8 | 1457.2 | 1835 | 886.2 |
| Bricks in vertical walls of the grain compartments | 166,347 | 166,347 | 107,052 | 107,052 | 135,577 | 90,385 | 120,513 | 57,052 |
| Bricks in vault ceilings of the grain compartments | 535,113 | 535,113 | 385,265 | 385,265 | 440,566 | 305,014 | 384,093 | 185,495 |
| Tot. no. of bricks for walls+vaulted ceilings of the grain compartments | 701,460 | 701,460 | 492,317 | 492,317 | 576,143 | 395,399 | 504,606 | 242,547 |

| | |
|---|---|
| Total number of compartment wall bricks | 950,325 |
| Total number of compartment vault bricks bricks | 3,155,924 |
| Total bricks required | 4,106,249 |

| | | | |
|---|---|---|---|
| **Compartment vertical walls** | | | |
| Total man-days required to make bricks for compartment vertical walls | 20,813 | man-days | |
| Total man-years required to make bricks for compartment vertical walls | 68 | man-years | |
| Total man-years to build walls of compartments+scafolding uplift | 43 | man-years | |
| Total man-years | **111** | man-years | |
| **Vault ceiling** | | | |
| Total man-days required to make bricks | 53,020 | man-days | |
| Total man-years required to make bricks | 173 | man-years | |
| Total man-years to build vaults | 280 | man-years | |
| Total Compartment vertical walls + vault ceiling | **453** | man-years | |
| | | | |
| Total man-years to make bricks for main walls + compartments | 439 | man-years | |
| Total man-years to lay bricks for main walls + compartments | 484 | man-years | |
| **Tot man-yrs to make and lay bricks for main walls+compartments** | **923** | man-years | |
| | | | |
| Density of dry barley | 609 | kg/m$^3$ | |
| Density of dry emmer wheat | 769 | kg/m$^3$ | |
| Density of dry pulses | 753 | kg/m$^3$ | http://www.ag.ndsu.edu/pubs/ansci/livestoc/as1282w.htm |
| Weight of the barley portion of the diet to feed 100,000 people | 14,640,060 | kg | |
| Weight of the emmer portion of the diet to feed 100,000 people | 4,879,819 | kg | |
| Weight of the pulses portion of the diet to feed 100,000 people | 13,702,488 | kg | |
| Total weight kg | 33,222,367 | kg | |
| Volume of barley m3 | 24,040 | m$^3$ | |
| Volume of emmer m3 | 6,346 | m$^3$ | |
| Volume of pulses m3 | 18,201 | m$^3$ | |
| Total volume m3 | 48,587 | m$^3$ | |
| Assume population at start NK | 1,250,000 | | |
| Assume population at end of NK | 2,200,000 | | |
| Assume redistribution tax % | 10 | | |
| Vol. stored in state granaries start NK | 60,734 | m$^3$ | |
| Vol. stored in state granaries end NK | 106,891 | m$^3$ | |
| Volume of Ramesseum granary m$^3$ | 16,522 | m$^3$ | |
| Equiv no. of Ram' granaries at start NK | **4** | | |
| Equiv no. of Ram' granaries at end NK | **7** | | |
| Total man-years | **6,461** | | |

**Report 5.9: Urban granaries in Amarna** — Assume bricks same size as Ramesseum granaries

| | | | |
|---|---|---|---|
| Average diameter of garnary silos at Amarna | 2.5 | m | Kemp 2000: 296. |
| Depth of granary | 1.9 | m | |
| Volume of granary silo | 9.5 | $m^3$ | Kemp 2000: 309. |

| | | |
|---|---|---|
| Volume of silo mud bricks | 3.5 | $m^3$ |
| No. of concentric brick courses | 2 | |

**Granaries based on size of Amarna circular silos**

| | | | |
|---|---|---|---|
| Weight of barley if granary held barley | 5,786 | kg | |
| Weight of wheat if granary held wheat | 7,306 | kg | |
| Weight of pulses if granary held pulses | 7,152 | kg | |
| Weight of the barley portion of the diet to feed 100,000 people | 14,640,060 | kg | |
| Weight of the emmer portion of the diet to feed 100,000 people | 4,879,819 | kg | |
| Weight of the pulses portion of the diet to feed 100,000 people | 13,702,488 | kg | |
| No. of granaries required to feed 100,000 with diet allocation of barley | 2,531 | | Total = |
| No. of granaries required to feed 100,000 with diet allocation of wheat | 668 | | 5,115 |
| No. of granaries required to feed 100,000 with diet allocation of pulses | 1,916 | | |
| No. of granaries required to feed 2,200,000 with diet allocation of barley | 55,682 | | Total = |
| No. of granaries required to feed 2,200,000 with diet allocation of wheat | 14,696 | | 112,530 |
| No. of granaries required to feed 2,200,000 with diet allocation of pulses | 42,152 | | |
| No. of mud bricks required for barley storage for population 2.2 million | 57,541,749 | | Total = |
| No. of mud bricks required for wheat storage for population 2.2 million | 15,186,839 | | 116,288,442 |
| No. of mud bricks required for pulses storage for population 2.2 million | 43,559,854 | | |

| | |
|---|---|
| Population at end of NK | 2,200,000 |
| Wt of grain and pulses to feed 100,000 million from AGCALC 2.20e | 33,222,367 |
| Total weight of grain and pulses to feed 2.2 million | 730,892,074 |
| Assumes average family size | 6 |
| No. of families with population 2,200,000 | 366,667 |
| Dome uplift | 1.2 |
| Total man-years uplifted for seed corn | 1.1 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Manpower to make bricks for the granaries | 6,112,121 | man-days | **19,845** | man-years | **21,830** | | **Average** | **20,838** | |
| Manpower to make bricks includes up lift for dome roof | 4,958,934 | man-days | **16,101** | man-years | **17,712** | | **Average** | **16,907** | |
| Total man-years | | | **35,946** | **man-years** | **39,542** | **man-years** | **Average** | **37,744** | |
| Per amarna granary | | | **0.32** | **man-years** | **0.35** | **man-years** | **Average** | **0.335** | **man-years** |

**SUMMARY OF CASE STUDY EXAMPLES**

| State Project | No. of bricks | Man-yrs to make bricks | Man-yrs to build structure | Total man-years |
|---|---|---|---|---|
| Enclosure wall built for the Middle Kindom town of Lahun. | 6,160,537 | 239 | 194 | 433 |
| Enclosure wall of the town of Sesebi (between the 2nd & 3rd cateracts) | 10,343,292 | 400 | 325 | 725 |
| Granary built for the Nubian fortress of Mirgissa | 9,446,157 | 862 | 1,397 | 2,259 |
| The Middle Kingdom fortress at Buhen | 13,318,057 | 1,216 | 1,969 | 3,185 |
| Granary at the Ramesseum | 4,106,249 | 439 | 484 | 923 |
| Total granaries (amarna design) to store grain/pulses to feed 2.2 million | 116,288,442 | 19,845 | 16,101 | 35,946 |

# BRONZECALC

## Summary: Man-years required to make the copper oxide and tin ingots excavated from the Ulu Burun Wreck

| SUMMARY CYPRUS | IMPORTED TIN | COPPER | BRONZE | TOTAL | % of Total |
|---|---|---|---|---|---|
| **Extraction of ore** | 281 | 153 | - | 434 | 8.3 |
| **Firesetting in Uzbekistan** | 33 | - | - | 33 | 0.6 |
| **Beneficiation** | 203 | 3334 | - | 3,537 | 67.9 |
| **Roasting of sulphide ore** | - | 21 | - | 21 | 0.4 |
| **Smelting ores** | 28 | 222 | - | 250 | 4.8 |
| **Refining** | - | 10 | - | 10 | 0.2 |
| **Alloying** | - | - | 4 | 4 | 0.1 |
| **Charcoal production** | 85 | 703 | 20 | 808 | 15.5 |
| **Transport and fodder costs** | 17 | 92 | 1 | 110 | 2.1 |
| TOTAL MAN-YEARS | 647 | 4,535 | 25 | 5,207 | 100 |
| SUMMARY TIMNA | IMPORTED TIN | COPPER | BRONZE | TOTAL | % of Total |
| **Extraction of ore** | 281 | 2,722 | - | 3,003 | 32.1 |
| **Firesetting in Uzbekistan** | 33 | - | - | 33 | 0.4 |
| **Beneficiation** | 203 | 3334 | - | 3,537 | 37.8 |
| **Roasting of sulphide ore** | - | - | - | 0 | - |
| **Smelting ores** | 28 | 222 | - | 250 | 2.7 |
| **Refining** | - | 12 | - | 12 | 0.1 |
| **Alloying** | - | - | 4 | 4 | 0 |
| **Charcoal production** | 100 | 819 | 20 | 939 | 10 |
| **Transport and fodder costs** | 19 | 1,557 | 1 | 1,577 | 16.9 |
| TOTAL MAN-YEARS | 664 | 8,666 | 25 | 9,355 | 100 |
| % cost of Timna compared with Cyprus | | 191 | Ratio | 0.56 | |

| | | | | |
|---|---|---|---|---|
| % increase cost Timna vs Cyprus | | **180** | Cypriot man-yrs/100,000 poplation | **2,604** |
| Ratio Timna to Cyprus | | **1.8** | Timna man-yrs/100,000 poplation | **425** |
| No. of seasons | 1 | 5 | Total Cypriot value add | **10,765** |
| Total man-years | 9,355 | 9,481 | Total Egyptian value add | **358,908** |
| man-yrs/kg bronze | 0.815 | 0.83 | Cypriot value add/100,000 populat'n | **4.1** |
| % increase over 5 seasons | | **1.34** | Egyptian value add/100,000 popul'n | **38.4** |

| | |
|---|---|
| % cost of producing bronze at Timna and alloying in PiRamesses compared to Cyprus | **180** |
| % cost of producing bronze in Cyprus compared with Timna and alloying in PiRamesses | **56** |
| % cost of producing copper at Timna compared to Cyprus | **191** |
| % cost of producing copper in Cyprus compared to Tima | **52** |

**Report 6.1: Summary of bronze production for Timna and Cyprus**

| | |
|---|---|
| Population of Egypt at end of New Kingdom | 2,200,000 |
| Production rate per annum | 100 |
| Min. weight of the Copper ingots on the Ulu Burun wreck | 9,525 |
| Max. weight of the Copper ingots on the Ulu Burun wreck | 10,478 |
| Total weight of the tin ingots on the Ulu Burun wreck | 1000 |
| Days available for working per year | 308 |
| Hours worked per day | 8 |
| Distance Uzbekistan to Ugarit | 2300 |
| Distance Ugarit to Piramesses | 900 |

**Report 6.1a: Man-days to make one kg copper**

| | man-days/kg |
|---|---|
| Man-days required to make one kg of copper in Cyprus | **134** |
| Man-days required to make 1 kg of copper in Timna | **255** |
| Percentage increase Timna over Cyprus | **191** |

**Report 6.1b: Man-years and man-days to make one kg copper**

| | man-years/kg |
|---|---|
| Man-years required to make one kg of copper in Cyprus | **0.433** |
| Man-years required to make 1 kg of copper in Timna | **0.827** |

**Report 6.1c: Percentage split of manpower by process operation**

| Percentage | Cyprus | Timna |
|---|---|---|
| Extraction of ore | 8.3 | 32.1 |
| Firesetting in Uzbekistan | 0.6 | 0.4 |
| Beneficiation | 67.9 | 37.8 |
| Roasting of sulphide ore | 0.4 | - |
| Smelting ores | 4.8 | 2.7 |
| Refining | 0.2 | 0.1 |
| Alloying | 0.1 | 0 |
| Charcoal production | 15.5 | 10 |
| Transport and fodder costs | 2.1 | 16.9 |
| **TOTAL** | **100** | **100** |

**Report 6.1d: Man-years required to make 2 deben of copper at Timna**

| | | |
|---|---|---|
| Weight of one deben | 0.091 | kg |
| Man-years to make 10,478 kg of copper | 8,666 | man-years |
| Man -years to make one deben | 0.0753 | man-years |
| Man -years to make two deben | 0.1506 | man-years |
| Man-years to make 5 deben | 0.3765 | man-years |

**Report 6.1e: Man-years required to make 2 deben of copper in Cyprus**

| | | |
|---|---|---|
| Weight of one deben | 0.091 | kg |
| Man-years to make 10,478 kg of copper | 4,535 | man-years |
| Man -years to make one deben | 0.0394 | man-years |
| Man -years to make two deben | 0.0788 | man-years |
| Man-years to make 5 deben | 0.197 | man-years |

**Report 6.1f: Days lost and available days for work**

| | | |
|---|---|---|
| Days lost due to sickness | 15 | days |
| Days lost for festivals festivals | 6 | days |
| Days lost due to one day per Egyptian week of 10 days | 36 | days |
| Available days for work | 308 | days |

**Report 6.1g: Cypriot man-years to make copper alone**

Cypriot man-years to make copper alone **4,535** man-years

# Module 1: Ore Requirements

| | | | | |
|---|---|---|---|---|
| **Number of Uluburuns** | 1 | 1 kg = | 2.20462 | lbs |

**Report 6.1.1: Number and weight of Ulu Burun copper ingots**

| | | | |
|---|---|---|---|
| Av. weight of 34 oxhide ingots measured | 24.61 | kg | Pulak 1997: 235-239 |
| Av. weight of 10 oxhide ingots measured | 22.88 | kg | Pulak 1997: 235-239 |
| Av. weight of 5 pillow shaped ingots | 10.75 | kg | Pulak 1997: 235-239 |
| No of oxhide ingots | 354 | | |
| No of intact Bun Cu Ingots | 121 | | |
| Equivalent no of bun ingots from fragments | 9 | | |
| Pillow shaped ingots (Av weight 10.75 kg) | 5 | | |
| Small copper oxhide ingot (KW 1983) | 1 | | |
| Total weight of Oxhide ingots | 8,750 | kg | Lin 2003: 206, Table 7.1. |
| Total weight of bun ingots | 775 | kg | Lin 2003: 206, Table 7.1. |
| Minimum weight of the Uluburun | 9,525 | kg | |
| Assume corrosion rate | 10 | % | |
| **Maximum uplifted weight of copper ingots** | 10,478 | kg | |

**Report 6.1.2: Volume of sulphide ores mined from the Troodos Mountains in Cyprus**

| | | | |
|---|---|---|---|
| Slag ore ratio | 1.2 | | Healy 1978:195, Rio Tinto Slag = 750,000 tons, produced from 900,000 tons of ore = ore to slag ratio 1.2 |
| % Cu in sulphide ore at Apliki | 1.8 | % | Bear 1963: 40, Table 10. |
| % Cu in sulphide ore at Apliki assumed for this model | 1.5 | % | |
| % recovery rate in smelting | 85 | % | Healy 1978:195 |
| Weight of sulphide ore to be extracted to make 1 kg copper | 78.4 | kgs of sulphide ore | |
| Density of Cu/Fe sulphide ores + gangue Mavrovouni and Kalavasos mines | 2265 | $kg/m^3$ | Bear 1963: 46 |
| Density of sandstone | 2320 | $kg/m^3$ | |
| Assumed depth of Gossan cap to be removed over laying the sulphide ore | 3 | m | |
| * Uplift ratio for gangue removed in refining | 1.1 | | |

Copper Development Association. 2008. Copper Production from Ore to Finished Product. Accessed 1/9/2007. Available from http://www.copper.org/education/production.html.

| | |
|---|---|
| length of one side = cube root m | 0.335 |
| Vol of gossan above ore vein $m^3$ | 0.336675 |
| Number of slices | 9 |
| Proportion of overhead of gossan to be removed $m^3$ | 0.0374 |

* The weight of sulphide ore 78.4 kgs to make one kg of copper refers to black copper. Black copper is the name given to copper that has been smelted. It containes many impurities that are subsequently removed in the refining process. As much of this is gangue the ore and gangue dug out would be slightly larger than calculated. This analysis has uplifted the result by 10%.

| | | |
|---|---|---|
| **Vol. of sulphide ore to be extracted to make 1 kg of black copper** | **0.0381** | $m^3$ |
| **Tot. vol. ore +proportion of overhead gossan to make 1 kg of refined Cu** | **0.0755** | **$m^3$ maximum** |

| Composition | Cu | $SiO_2$ | Other | References |
|---|---|---|---|---|
| % Cu in best nodules | 45 | 30 | 25 | Merkel 1983a: 174 |
| Average % Cu bulk ore | 12 | 60 | 28 | Merkel 1985: 165 |
| Average % Cu after beneficiation | 18 | | | Merkel 1985: 165 |
| % recovery rate in smelting | 85 | | | Healy 1977:195 |

**Report 6.1.3: Case C - volume of sandstone beds mined at Timna that contained copper ores**

Ref. Batura et al 1980: 41-56.

Assume average height of tunnel m = 1 Rothenberg 1962: 9-10.

**Percentage copper in ore after beneficiation**

| kg/ $m^3$ Cu ore in tunnel | % Cu in ore after beneficiation |
|---|---|
| 6 | 0.1 |
| 15.3 | 0.3 |
| 6.3 | 0.2 |
| 20 | 0.3 |

| | | | |
|---|---|---|---|
| Best | 10 | 0.31 | 3.1 |
| Average | 40 | 0.23 | 9.2 |
| Poor | 50 | 0.14 | 7 |
| | 100 | | 19.3 |

**Wt of ore to make 1 kg black copper** **5.18134715**

**Vol. of ore to make 1 kg blacl copper** **0.002233339** $m^3$

**Volume of ore excavated to make 1 kg ore assuming above copper concentration in ore**

| | Volume of gallery $m^3$ | kg/ $m^3$ Cu ore in tunnel | % Potential Cu in ore | Gross Cu potential from the gallery kg | Cu recovery after smelting 85% recovery kg | Cu recovery after smelting kg/$m^3$ of tunnel | Vol of ore + gangue $m^3$ to make 1 kg Cu |
|---|---|---|---|---|---|---|---|
| Area A | 42.8 | 6 | 0.1 | 25.7 | 21.8 | 0.509345794 | 1.963302752 |
| Area B | 8.3 | 15.3 | 0.3 | 38.1 | 32.4 | 3.903614458 | 0.25617284 |
| Area C | 6.3 | 6.3 | 0.2 | 7.9 | 6.7 | 1.063492063 | 0.940298507 |
| Area D | 41 | 20 | 0.3 | 246 | 209.1 | 5.1 | 0.196078431 |

**Average vol of ore + gangue to make 1 kg of black copper** **0.84** $m^3$

Uplift ratio for additional gangur removal in the refing process 1.1

**Average vol of ore + gangue to make 1 kg of refined copper** **0.924** $m^3$

**Volume of ore excavated to make 1 kg ore assuming Merkel's experimental archaeology results for beneficiation**

| | Volume of gallery $m^3$ | kg/ $m^3$ Cu ore in tunnel | % Potential Cu in ore | Gross Cu potential from the gallery kg | Cu recovery after smelting 85% recovery kg | Cu recovery after smelting kg/$m^3$ of tunnel | Vol of ore + gangue $m^3$ to make 1 kg Cu |
|---|---|---|---|---|---|---|---|
| Area A | 42.8 | 6 | 0.12 | 30.8 | 26.2 | 0.612149533 | 1.633587786 |
| Area B | 8.3 | 15.3 | 0.12 | 15.2 | 12.9 | 1.554216867 | 0.643410853 |
| Area C | 6.3 | 6.3 | 0.12 | 4.8 | 4.1 | 0.650793651 | 1.536585366 |
| Area D | 41 | 20 | 0.12 | 98.4 | 83.6 | 2.03902439 | 0.490430622 |

**Average vol of ore + gangue to make 1 kg of black copper** **1.08** $m^3$

Uplift ratio for additional gangue removal in the refining process 1.10

**Average vol of ore + gangue to make 1 kg of refined copper** **1.19** $m^3$

**Report 6.1.4: Case D - volume of granite/quartz tin ore bearing rocks in Central Asia**

| | | |
|---|---|---|
| Ref. data Cierny & Weisgerber 2003: 27 | | |
| Density of granite solid | 2,691 | $kg/m^3$ |
| Density of quatz solid | 2,643 | $kg/m^3$ |
| Weight of rock cut out | 730 | tons |

**Trench dimensions**

| | | |
|---|---|---|
| Depth of trench | 15 | m |
| Width | 0.6 | m |
| Length | 30 | m |
| Vol of trench | 270 | $m^3$ |

**Ore vein dimensions**

| | | | | |
|---|---|---|---|---|
| Average thickness of vein | 0.075 | m | Cierny and Weisgerber 2003: 25. | |
| Depth | 15 | m | | |
| Length | 30 | m | | |
| Vol. of ore | 33.75 | $m^3$ | | |
| Density of Cassiterite | 7,000 | $kg/m^3$ | | |
| Wt of ore extracted | 236,250 | kg | | |
| | 105.5 | tons | | |
| Tin concentration | 2 | % min | 4 | % min |
| Weight of tin potential | 4,725 | kg | 9,450 | kg |
| | 2.109375 | tons | 4.21875 | tons |
| **Volume of trench removed to produce 1 kg tin** | **0.0571** | **$m^3/kg$** | **0.0286** | **$m^3/kg$** |
| **Weight of ore to produce 1 kg tin** | **50** | **kg** | **25** | **kg** |

# Module 2: Mining

## Man-years required to extract sufficient ore to produce Ulu Burun Copper Ingots

**Report 6.2.1: Assumptions used for mining analysis**

| | | |
|---|---|---|
| Minimum weight of Cu found on the Ulu Burun wreck | 9525 | kg |
| Maximum weight of Cu found on the Ulu Burun wreck | 10,478 | kg |
| Assume shift | 8 | hrs |

| | Central asia | Cyprus | Timna |
|---|---|---|---|
| No. of men at the pit face or digging ore from open cast pit | 1 | 1 | 1 |
| **Support team** | | | |
| Man filling basket supporting the digger | 1 | 1 | 1 |
| No. of men carrying baskets to mine shaft or lifting ore out of open cast pit | 1 | 3 | 2 |
| No. of men filling up excvated galleries with gangue or taking to dump | 1 | - | 2 |
| No. of men lifting ore up the mine shaft | 2 | - | 2 |
| **Total support manpower per shift** | **5** | **4** | **7** |
| **Total manpower per shift** | **6** | **5** | **8** |

Hayes 1942: 21.

| | | |
|---|---|---|
| Assume shift | 8 | hrs |
| No. of men in tomb | 11 | |
| Height | 0.65 | m |
| Width | 3.9 | m |
| Daily movement of tunnel 8 hrs shift with 11 men | 0.52 | m |
| Volume removed per day by 11 men | 1.319 | $m^3$ |
| Assume max no. of men cutting the rock | 5 | |
| Volume of ore removed by one worker/day | 0.264 | $m^3$ |
| Output ratio to reflect the cramped conditions/poor ventilation at Timna | 0.45 | |
| Min. removal rate of ore removed by one worker/day | 0.119 | $m^3$/day |

| **Analysis of donkey effort to move tin from Ubekistan** | |
|---|---|
| donkey trips | 1,067 |
| donkey-days | 894 |
| **donkey-years** | **3** |

**Report 6.2.5: Preparing faggots for firesetting**

Average of 66 experiments Py and Ancel 2006: 78, figure 4

| | | |
|---|---|---|
| Weight of wood burnt | 59.7 | kg |
| Weight of Rock extracted | 37.4 | kg |
| Weight of wood per kg ore | 1.6 | kg |
| Weight of ore per kg tin | 50 | kg |
| Weight of wood per kg tin | 80 | kg |
| Total wt. wood for Ulu Burun tin | 80000 | kg |
| Wt of branches from a tree | 38 | kg |
| No. of trees | 2106 | |
| No. of hours to cut and stack wood | 6.5 | hrs |
| No. of man days to cut wood | 1,711 | man-days |
| **No. of man-years to cut wood** | **6** | **man-days** |
| Carrying capacity of donkeys | 75 | kg |
| Number of donkeys | 1067 | |
| No of donkeys in train | 10 | |
| No. of donkey trips | 107 | |
| Speed of donkey train | 4.48 | km/hr |
| Distance forest from mine | 15 | km |
| Time for return journey | 6.7 | hrs |
| Number of donkey handlers per train | 2 | |
| Total man-hours | 180 | man-days |
| | **1** | **man-years** |
| **Total man-years** | **7** | **man-years** |

**Report 6.2.6: Firesetting**

| | | |
|---|---|---|
| No. of man-days arranging faggots and monitoring fire | 4 | man-days |
| No. of man-days carrying water to site | 2 | man-days |
| **Total man-days** | **6** | **man-days** |
| Tot. wt. of ore excavated to make tin ingots on the Ulu Burun | 50000 | kg |
| No. of cycles required | 1337 | |
| Total man-days | 8022 | man-days |
| **Firesetting man-years** | **27** | **man-years** |
| **Total man-years associated with firesetting** | **33** | **man-years** |

**Report 6.2.3: Ardaillon's assumptions for Laurian extraction rates (Ardaillon 1897: 25-260.**

| Ardaillon's assumptions for Laurian extraction rates | |
|---|---|
| Height | 0.6 |
| Width | 0.6 |
| Daily movement of tunnel 8 hrs shift per team | 0.011 |
| Volume of ore + rock removed per day per team | 0.00396 |
| Volume of ore required to make 1 kg copper cu m | 0.0755 |
| Digging man-days required to extract ore to produce 1 kg refined ore | 19.07 |
| Daily digging rate $m^3$/dayto produce 1 kg refined copper | 0.003959 |
| **Digging man-days + team required to extract ore to dig 1 kg refined ore** | **95.35** |
| Man days required to extract ore to make copper excavated from the Ulu Burun | 999,077 |
| **Man-years required to extract ore to produce Ulu Burun Copper ingots** | **3,243.8** |

**Report 6.2.4: Evidence used from Overtom Down experiment (Jewell 1968: 50-64)**

| | | |
|---|---|---|
| Measured removal rate | 3 | ft3/hr/man |
| | 0.0849 | $m^3$/hr |
| | 0.509 | $m^3$/day |
| On-site density of chalk | 1795 | kg/$m^3$ |
| Density chalcocite sulphid ore | 5700 | kg/$m^3$ |
| Ratio of densities | 3.18 | |
| Max removal rate inversely prop'tional to densities | 0.16 | $m^3$/day |
| A man could not continuously sustain this rate so the daily rate has been utilised assuming that 2 hrs of the 8 hr day is resting | | Effective day hrs |
| | | 6 |
| Assume for every m depth of sulphide ore excavated an equal depth of gossan is removed from above the ore bed | | |
| Effective rate therefore | | 0.5 |
| Min removal rate inversely prop'tional to densities | 0.08 | $m^3$/day |

SUMMARY EXTRACTION TIME

| | Tin | | Copper | | | |
|---|---|---|---|---|---|---|
| Summary of the volume of ore and gangue and their respective extraction rates and manpoer requirements to make one kg of copper or tin. | **Central Asia tin ore + gangue excavation rate based on Ardaillon's evidence** | | **Cyprus copper ore + gangue based on Overton Down experiment** | | **Timna copper + gangue based on Senenmut's evidence** | |
| Volume of ore required to make 1 kg of metal $m^3$ | | 0.0571 | | 0.0755 | | 1.19 |
| Volume of ore removed by one worker/day | | 0.003959098 | | 0.08 | | 0.119 |
| Days required to extract sufficient ore to make 1 kg Copper/digger | | 14.4 | | 0.9 | | 10 |
| Total mining team manpower (days) | | 86.4 | | 4.5 | | 80 |
| **Total mining team manpower (man-years)** | | 0.281 | | 0.015 | | 0.26 |

| | Tin | Copper | |
|---|---|---|---|
| Summary of the manpower required to make the copper and tin ingots on the Ulu Burun | **Central Asia tin ore + gangue excavation rate based on Ardaillon's evidence** | **Cyprus copper ore + gangue based on Overton Down experiment** | **Timna copper + gangue based on Senenmut's evidence** |
| **Man-days required to extract ore to make copper equiv. Ulu Burun ingots** | **86,400** | **47,151** | **838,240** |
| **Man-years required to extract ore to make copper equiv. Ulu Burun ingots** | **281** | **153** | **2,722** |

| Ore extraction man-years | | |
|---|---|---|
| Copper | | Tin |
| Cyprus | Timna | Central Asia |
| **153** | **2,722** | **281** |

# Module 3: Preparation of sulphide ores

**Report 6.3.1: Manpower required for beneficiation**

| | Manpower cost | | | |
|---|---|---|---|---|
| | Copper | Tin | | |
| Wt of ore to make 1 kg of smelted metal | 78.4 | 50.0 | kg | |
| Donnovans experimental beneficiation results | 0.8 | 0.8 | kg/hr | Doonan 1994: 86-87, Table 3. |
| Days to collect/grind ore charge + crush flux and charcoal | 98 | 62.5 | days | |
| Total ore required to make Ulu Burun ingots | 821,475 | 50,000 | kg | |
| Total number of man-days for beneficiation | 1,026,844 | 62,500 | | |
| Man-days per kg of copper produced | 98 | 63 | man-days | |
| **No of man years** | **3334** | **203** | **man-years** | |

| | |
|---|---|
| Hours worked per day | 8 |
| Days available for working/year | 308 |
| Weight kg of Ulu Burun tin ingots | 1,000 |
| Ore to make one kg tin | 50 |

| | |
|---|---|
| individual donkey trips | 3046 |
| donkey-days | 2730 |
| donkey-years | 8 |

**Report 6.3.2: Manpower required for roasting sulphide ores**

| | Roasting | |
|---|---|---|
| **Roasting** | **Manpower cost** | |
| Wt of ore roasted to make 1 kg of ore | 78.4 | |
| Vol of ore roasted to make 1 kg black copper | 0.0381 | $m^3$ |
| Vol of Ore Roasted to produce Uluburun Ingots | 399.2 | $m^3$ |
| Diameter of mound | 2 | m |
| Height of mound | 1.5 | m |
| Assume mound 3.5m diameter and 2 m height then volume | 2.095 | $m^3$ |
| Number of mounds rounding up | 191 | |
| No of days roasting | 15 | days |
| Minimum number of men roasting | 2 | |
| **Total man-days to monitor roasting process** | **5,730** | **man-days** |
| **Total man-days for roasting process+grinding copper matte** | **21** | **man-years** |

| Crushing and grinding Cu matte | | |
|---|---|---|
| **Manpower cost** | | |
| Percentage uplift | 10 | % |
| Man-days for grinding/crushing matte | 573 | man-years |

**Report 6.3.3: Manpower required for lumbering the wood required for roasting sulphide ores**

| | | | |
|---|---|---|---|
| Weight of oak required to roast ore to produce 1kg copper | 21.8 | kg | Allan 1970: 10 |
| Total wt. of oak wood to roast ore to make the Ulu Burun copper ingots (Density of dwalf oak 690 kg/$m^3$) | 228421 | kg | |
| Voumel of wood required | 331 | $m^3$ | |
| Total weight of wood required | 228,390 | kg | |
| Weight of wood from suitable size tree | 38 | kg | |
| Total number of trees required felling | 6011 | | |
| Number of hours to cut and stack wood | 6.5 | hrs | |
| **No. of man days to cut wood** | **4,884** | **man-days** | |

**Report: 6.3.4: Manpower required for transporting wood from the lumbering site to the roasting site**

| Transport cost by donkey train | Man-days | |
|---|---|---|
| Distance to carry wood to roasting centre | 15 | km |
| Total weight of wood required | 228,390 | miles/hr |
| Carrying capacity of donkeys | 75 | kg |
| Number of donkeys | 3046 | |
| No of donkeys in train | 10 | |
| No. of donkey trips | 305 | |
| Speed of donkey train | 0 | km/hr |
| Distance forest from mine | 15 | km |
| Time for return journey | 4.48 | hrs |
| Number of donkey handlers per train | 2 | |
| Total man-hours | 342 | man-days |
| Total man-years | **2** | **man-years** |
| **Man-days transporting wood for roasting** | **2** | **man-days** |

| | | |
|---|---|---|
| **Man-days lumbering + transport to roasting centre + roasting monitoring** | **10956** | **man-days** |
| **Man-years lumbering + transport to roasting centre + roasting monitoring** | **36** | **man-years** |

# Module 4a: Smelting copper ores

**MERKEL'S REFINING EXPERIMENTS USING ORES FROM TIMNA** Ref Merkel 1983: 7, Table 1.

| | | |
|---|---|---|
| Available days for work | 308 | days |
| Hours worked per day | 8 | hrs |
| Minumum weight of Ulu Burun copper ingots | 9,525 | kg |
| Maximum weight of Ulu Burun copper ingots | 10,478 | kg |

**Report 6.4.1: Manpower required for acquiring iron oxide flux from the gossan**

| | Minimum | Maximum | | |
|---|---|---|---|---|
| Ratio of iron oxide flux to copper ore | 3 | 3 | | Merkel 1985: 226-227. |
| Weight of ore required to make 1 kg copper | 78.4 | 78.4 | kg | |
| Weight of ore required to make 1 kg copper | 235 | 235 | kg | |
| Total flux requirement to make Cu on the Uluburun | 2,240,280 | 2,464,426 | kg | |
| Volume of flux | 934 | 1,027 | $m^3$ | |
| Digging rate of chslk (nearest equiv't to the compaction of the gossan) | 3 | 3 | $m^3$/man-hr | Jewell 1963: 50-64. |
| | 0.679604318 | 0.679604318 | $m^3$/man-day | |
| Man-days to dig sufficient flux required/kg of copper | 1.154 | 1.154 | | |
| Man-days to dig flux to make the Ulu Burun copper ingots | 1374.4 | 1511.2 | man-days | |
| Digging uplifted for crushing and moving to smelting site | **4** | **5** | **man-years** | |

**Density**

| | | |
|---|---|---|
| Iron Pyrites | 2400 | $kg/m^3$ |
| Chalk | 2500 | $kg/m^3$ |

**Report 6.4.2: Manpower required for smelting copper ore**

| | | | | |
|---|---|---|---|---|
| Total elapse time for smelting | 8 | 8 | hrs | Tylecote 1980a: 5-12 and Merkel 1990: 86, tables 1 and 2. |
| | 1 | 1 | days | |
| Total number of men required for the smelting process | 3 | 5 | | |
| Wt of Cu smelted | 1.1 | 1.1 | kg | Merkel 1989: 222-223, Table 1. |
| Man-days required to smelt one kg of copper | 2.8 | 4.6 | | |
| No of smelts required to produce the Ulu Burun copper ingots | 8,659 | 9,525 | | |
| Total man-days required to smelt the Ulu Burun copper ingots | 25,977 | 47,627 | man-days | |
| **No of man years** | **85** | **155** | **man-years** | |

| Tot. no.of men required for the smelting process | Minimum | Maximum |
|---|---|---|
| Men operating the bellows in shifts of two | 2 | 3 |
| Bellow operator resting | | 1 |
| Furnace stoker | 1 | 1 |
| Total | 3 | 5 |

**Report 6.4.3: Buiilding, breaking down after smelting + repairs to furnace**

| | | | |
|---|---|---|---|
| Assume number of man-days/furnace | 1 | 2 | man-days |
| Man-days required to produce the copper ingots on the Ulu Burun | 8,659 | 19,051 | man-days |
| Man-years required to produce the copper ingots on the Ulu Burun | **29** | **62** | **man-years** |

**Report 6.4.4: Total manpower for fluxing, smelting and furnace repairs**

| | Maximum | | Minimum | |
|---|---|---|---|---|
| No. of smelts required to produce the copper ingots on the Ulu Burun | 9,525 | | 8,659 | |
| Total man-days required to smelt one kg of copper | 7 | man-days | 4 | man-days |
| Total man-days required to smelt the copper ingots on the Ulu Burun | 68,376 | man-days | 36,344 | man-days |
| **Tot. man-years req'd to smelt the copper ingots on the Ulu Burun** | **222** | **man-years** | **118** | **man-years** |

# Smelting tin ores

**Report 6.4.5: Manpower required for smelting tin ore**

| | | | |
|---|---|---|---|
| **Timberlake's experiments 22/5/1994** | | | |
| Time for bringing crucible furnace up to temperature | 1 | hrs | Timberlake 1994: 124. |
| Total elapse time for smelting | 1.25 | hrs | |
| Period extracting prills from crucible charge remains | 0.5 | hrs | |
| Total smelting and prill extraction period | 2.75 | hrs | |
| No. of men operating tuyeres and belows | 1 | | |
| | 0.15625 | days | |
| Minimum number of men | 2 | | |
| Wt of Sn ore | 0.25 | kg | Timberlake 1994: 125. |
| Percentage of tin in casserite ore | 60 | % | Timberlake 1994: 123. |
| Wt of recovered tin | 0.128 | kg | Timberlake 1994: 125. |
| Percentage of tin recovered | 51.2 | % | |
| Charcoal used | 15 | kg | |
| Charcoal required to smelt one kg of tin ore | 70 | kg | |
| **Timberlake'sTime Team Experiments 1995 at Lamora, Penzance** | | | |
| Wt of Sn ore | 0.2 | kg | Poscript Timberlake 1994: 127 |
| Percentage of tin in casserite ore | 65 | % | Poscript Timberlake 1994: 127 |
| Wt of recovered tin | 0.08 | kg | Poscript Timberlake 1994: 127 |
| Percentage of tin recovered | 40 | % | |
| **Applying Timberlake's experimental findings to smelting the tin ingots on the Ulu Burun** | | | |
| No. of working hours/day | 8 | hrs | |
| No. of days worked per year | 308 | days | |
| Weight of tin ingots on the Ulu Burun | 1,000 | | Pulak 2000c: 152. |
| No of smelts required to produce 1000 kg tin ingots on the Ulu Burun | 12,500 | | Poscript Timberlake 1994: X. |
| No. of smelts required to produce the 1000 kg of tin on the Ulu Burun | 12,500 | | |
| Total man-days required to one kg of tin | 8.6 | man-days | |
| Total man-days required to smelt the tin ingots on the Ulu Burun | 8,594 | man-days | |
| **Total man-years to smelt the tin ingots on the Ulu Burun wreck** | **28** | **man-years** | |

**Summary**

| | | |
|---|---|---|
| Minimum charcoal used to smelt one kg of tin | 60 | kg |
| Maximum charcoal used to smelt one kg of tin | 80 | kg |
| Average wt of charcoal to melt one kg of tin | 70 | kg |

# Module 5: Refining and alloying copper and tin

**Report 6.5.1: Improving copper purity through refining**

Reference Merkel 1983a: 177, Table 1.

| | Stage 1 | Stage 2 | Stage 3 | Stage 4 | Stage 5 |
|---|---|---|---|---|---|
| | Smelted Cu % | Smelted Cu % | Smelted Cu % | Smelted Cu % | Smelted Cu % |
| Cu | 74.9 | 92.6 | | | 99.7 |
| Fe | 22.2 | 6.2 | 3 | 2 | 0.014 |
| S | 0.49 | 0.18 | | | 0.02 |
| As | 0.15 | 0.22 | | | 0.14 |
| other | 2.26 | 0.8 | | | 0.126 |
| Total | 100 | 100 | | | 100 |

**Report 6.5.2: Manpower required to refine copper and alloying with tin**

| REFINING BLACK COPPER | Cyprus | | Pi-Ramesses | | Units | |
|---|---|---|---|---|---|---|
| | Min. cost | Max. cost | Min. cost | Max. cost | | |
| Minimum number of men | 3 | 4 | 4 | 5 | | |
| Wt of Cu refined | 28 | 28 | 20 | 20 | kg | |
| Cycles required to refine the equiv. wt. of copper on the Ulu Burun | 340 | 374 | 476 | 524 | | |
| No of refinings per cycle | 4 | 5 | 4 | 5 | | |
| Time to preheat cruicible/clay lining | 1 | 1 | 0.32 | 0.32 | hr | |
| Time to melt copper, add flux, poling and remove the melt to repair fire | 2 | 2 | 1.43 | 1.43 | hr | Merkel 1983b: Table 31 Experiments 28-29. |
| Preheat time cruicible/clay lining and repair fire between refining cycles | 0.2 | 0.2 | 0.2 | 0.2 | hr | |
| Total elapse time for one refining cycle | 9.6 | 11.8 | 6.64 | 8.27 | hrs | |
| Total elapse time to refine the equiv. wt. of copper on the Ulu Burun | 3264 | 4413.2 | 3160.64 | 4333.48 | hrs | |
| No of man-days | 1632 | 2942 | 2107 | 3611 | man-days | |
| **No of man-years** | **6** | **10** | **7** | **12** | **man-years** | |
| **No. man-days per kg of copper refined** | **0.18** | **0.31** | **0.23** | **0.38** | **man-days/kg** | |

**Report 6.5.3: Volume of Merkel's shaft furnace and reconstructed crucible furnace excavated at Piramesses**

Fuel to ore ratio 3 Merkel 1989: 221

| Merkels shaft firnace. Dimensions taken from Merkel 1990: 85, figure 111 | Co-ordinates | | | Volume $m^3$ |
|---|---|---|---|---|
| | X | Y | Z | |
| Section 1 | 0.4 | 1.7 | 0.9 | 0.612 |
| Section 2 | 0.18 | 0.9 | 0.9 | 0.146 |
| Section 3 | 0.22 | 0.8 | 0.9 | 0.158 |
| Section 4 | 0.12 | 0.4 | 0.9 | 0.043 |
| | | | | **0.959** |
| **Piramesses furnace. Dimensions taken from Pusch 1994: 153, figure 1..** | 0.22 | 0.67 | 0.6 | **0.088** |

**Report 6.5.4: Estimate the weight of black copper refined per cycle at Piramesses**

| | | |
|---|---|---|
| Diameter of crucible at Piramesses | 0.14 | m |
| Approximate volume | 0.005747765 | $m^3$ |
| Assume proportion of copper to charcoal in the cruicible | 50 | |
| Volume refined per cycle | 0.002873883 | $m^3$ |
| Density of copper | 8920 | |
| Assume porosity, sulphur and slag inclusions | 22 | % |
| Density of black copper | 6957.6 | $kg/m^3$ |
| Wt of copper refined per cycle | 20 | kg |

| | | |
|---|---|---|
| Ratio thermal capacitance Merkels furnace shaft | 11 | |
| Time to preheat Merkel's furnace experiment 31 | 3.5 | hrs |
| Estimated time to pre-heat Piramesses furnace | 0.32 | hrs |
| Time to melt copper Merkels experiment | 3 | hrs |

Reference Merkel 1990: 131.

**Report 6.5.5: Alloying copper and tin**

| ALLOYING WITH TIN COPPER TO MAKE BRONZE | Cyprus | | Pi-Ramesses | | Units |
|---|---|---|---|---|---|
| | Min. cost | Max. cost | Min. cost | Max. cost | |
| Minimum number of men | 3 | 4 | 4 | 5 | |
| Wt of Bronze alloyed | 28 | 28 | 20 | 20 | kg |
| Alloying cycles required for the equiv. wt. of tin+copper on the U'Burun | 410 | 410 | 574 | 574 | |
| Time to preheat cruicible/clay lining | 1 | 1 | 0.32 | 0.32 | hrs |
| Time to melt copper, add flux, poling and maintan fire | 3 | 3 | 2.14 | 2.14 | hrs |
| Total elapse time for one cycle | 4 | 4 | 2.46 | 2.46 | hrs |
| Tot elapse time to alloy the equiv. wt. of tin+copper on the U'Burun | 1640 | 1640 | 1413 | 1413 | hrs |
| No of man-days | 820 | 1094 | 942 | 1178 | man-days |
| **No of man-years** | **3** | 4 | **4** | 4 | **man-years** |
| **No. man-days per kg of copper refined** | **0.087** | **0.115** | **0.099** | **0.124** | **man-days/kg** |

Reference Merkel 1983b: Table 31

# Module 6: Transportation

| | | |
|---|---|---|
| Available days for work | 308 | days |
| Hours worked per day | 8 | hrs |
| Minimum weight of the Ulu Burun copper ingots | 9,525 | kg |
| Maximum weight of the Ulu Burun copper ingots | 10,478 | kg |
| Weight of the tin ingots on the Ulu Burun | 1,000 | kg |
| Carrying capacity of a donkey | 75 | kg |
| No. of donkeys in train | 10 | |

* Note charcoal cost for tin is within charcoal worksheet and summary chart subtracts this to avoid double counting

** Assumes tin transported from Ugarit to Egypt via coatal route 700-750 km approximateley

*** Assumes long distance journey requires one donkey for fodder + supplies

**** Assumes return journey bring back independent economic load

| | | | | |
|---|---|---|---|---|
| Speed of donkey | 2.8 | mph | 4.48 | km/hr |
| No. handlers per donkey team | 2 | | | |

**Report 6.6.1: Transportation costs for transporting tin from Uzbekistan to Ugarit (route 1)**

| TRANSPORTATION COSTS | Uzbekistan-Ugarit | | Route 1 |
|---|---|---|---|
| | **Min. cost** | **Max. cost** | |
| **Manpower to control donkey teams** | | | |
| Wt of Ulu Burun tin ingots | 1,000 | 1,000 | kg |
| Carrying capacity of a donkey | 75 | 75 | kg |
| Number of donkeys required to carry the tin | 14 | 14 | |
| Minimum number of donkeys for supplies | 1 | 1 | |
| Assume no of donkeys per donkey train | 10 | 10 | |
| Number of donkey trains within the caravan | 2 | 2 | |
| No of handlers required to control donkey team | 2 | 2 | |
| Total number of handlers | 4 | 4 | |
| Distance to transport tin | 2,300 | 2,300 | km |
| Speed of donkey team | 2.8 | 2.8 | mph |
| Speed of donkey team | 4.48 | 4.48 | km/hr |
| Elapse time of journey | 513 | 513 | hrs |
| Length of shift | 8 | 8 | hrs |
| Watering/rest period | 1 | 1 | hrs |
| Length of shift less watering//rest period | 5 | 5 | hrs |
| No of days to travel to port | 103 | 103 | days |
| Tot. man-days for controlling donkey teams for single jouney | 412 | 412 | man-days |
| Tot. man-years for controlling donkey teams for single jouney | **2.0** | **2.0** | **man-years** |
| **Security** | | | |
| No. of soldiers per caravan | 25 | 25 | soldiers |
| Elapse time of journey | 103 | 103 | days |
| Total security man-days | 2,575 | 2,575 | man-days |
| Total security man-years | 9 | 9 | man years |
| **COST OF SECURITY + DONKEY HANDLERS** | **11** | **11** | **man-years** |
| Tot man-days for transport+security to transport tin equiv to Ulu Burun | 2,987 | 2,987 | man-days |
| Tot man-days for transport+security to transport tin per kg of tin | 2.99 | 2.99 | man-days |

| % number of additional donkeys required for supplies | | 5 |
|---|---|---|
| | Minimum | Maximum |
| individual donkeys | 15 | 15 |
| donkey-days | 1,545 | 1,545 |
| donkey-years | 5 | 5 |

| | | |
|---|---|---|
| **Distance travelled** | **2,300** | |
| Watering/rest stops/day | | 3 |
| Man-days per kg tin | 0.41 | 0.41 |
| Man-days per kg tin | 2.58 | 2.58 |

**Report 6.6.2: Transportation costs for transporting tin from Uzbekistan to Piramesses via Ugarit (routes 1 and 6)**

| TRANSPORTATION COSTS | Uzbekistan to Piramesses<br>Routes 1 and 6 via Ugarit | |
|---|---|---|
| **Manpower to control donkey teams** | | |
| Wt of Ulu Burun tin ingots | 1,000 | kg |
| Carrying capacity of a donkey | 75 | kg |
| Number of donkeys required to carry the tin | 14 | |
| Minimum number of donkeys for supplies | 1 | |
| Assume no of donkeys per donkey train | 10 | |
| Number of donkey trains within the caravan | 2 | |
| No of handlers required to control one donkey team | 2 | |
| Total number of handlers | 4 | |
| Distance to transport tin from Uzbekistan to Piramesses via Ugarit | 900 | km |
| Speed of donkey team | 2.8 | mph |
| Speed of donkey team | 4.48 | km/hr |
| Elapse time of journey | 201 | hrs |
| Length of shift | 8 | hrs |
| Watering/rest period | 1 | hrs |
| Length of shift less watering//rest period | 5 | hrs |
| No of days to travel to port single journey | 41 | days |
| Tot. man-days for controlling donkey teams for single jouney | 164 | man-days |
| Tot. man-years for controlling donkey teams for single jouney | 1 | **man-years** |
| **Security** | | |
| No. of soldiers per caravan | 25 | soldiers |
| Elapse time of journey | 41 | days |
| Total security man-days | 1,025 | man-days |
| Total security man-years | **4.0** | man years |
| **COST OF SECURITY + DONKEY HANDLERS** | **5** | **man-years** |
| **Distance travelled routes 1+6** | **3,200** | |
| Tot man-days for transport+security to transport tin equiv to Ulu Burun | 1,189 | man-days |
| Tot man-days for transport+security to transport tin per kg of tin | 1.19 | man-days |
| | Minimum | |
| Total number of donkeys | 15 | |
| donkey-days | 615 | |
| **donkey-years** | **2** | |

**Report 6.6.3: Tin content of tribute paid by bronze smiths from Ugarit to the Hitties**

| | | | |
|---|---|---|---|
| Bronze tribute paid to Hitties per bronze smith ranged from | 500 | 2000 | shekels |
| | 4.7 | 18.8 | kg |
| Weight of tin within bronze ranged from | 0.47 | 1.88 | kg |

**Report 6.6.4 : Costs incurred travelling from Ugarit to Cyprus (routes 2 and 3)**

| | | Route 2 | Route 3 |
|---|---|---|---|
| Distance by sea from Ugarit to Enkomi and Kition. | | 175 | 950 |
| Overland cost less security man-days | | **9** | **49** |
| Ratio land to sea | | 28 | 28 |
| Equivalent sea cost man-days | | **0.4** | **1.8** |
| Weight of Uratic shekel | 0.0094 | kg | |
| Assume tin content | 10 | % | |

**Report 6.6.5: Transportation costs for carrying black copper from Apliki to Enkomi (route 4)**

| TRANSPORTATION COSTS | Apliki to Enkomi | | Route 4 |
|---|---|---|---|
| | Min. cost | Max. cost | |
| **Manpower to control donkey teams** | | | |
| Wt of Ulu Burun copper ingots | 9,525 | 10,478 | kg |
| Carrying capacity of a donkey | 75 | 75 | kg |
| Number of donkeys required to carry the tin | 75 | 110 | |
| Minimum number of donkeys for supplies | 4 | 6 | |
| Assume no of donkeys per donkey train | 10 | 10 | |
| Number of donkey trains within the caravan | 8 | 12 | |
| No of handlers required to control one donkey team | 2 | 2 | |
| Total number of handlers | 16 | 24 | |
| Distance to transport copper Apliki to Enkomi in Cyprus | 150 | 175 | km |
| Speed of donkey team | 2.8 | 2.8 | mph |
| Speed of donkey team | 4.48 | 4.48 | km/hr |
| Elapse time of journey | 33 | 39 | hrs |
| Length of shift | 8 | 8 | hrs |
| Watering/rest period | 1 | 1 | hrs |
| Length of shift less watering//rest period | 5 | 5 | hrs |
| No of days to travel to port single journey | 7 | 8 | days |
| Tot. man-days for controlling donkey teams for single jouney | 112 | 192 | man-days |
| Tot. man-years for controlling donkey teams for single jouney | **0.4** | **0.7** | **man-years** |
| **Security** | | | |
| No. of soldiers per caravan | 25 | 25 | soldiers |
| Elapse time of journey | 7 | 8 | days |
| Total security man-days | 175 | 200 | man-days |
| Total security man-years | **0.6** | **0.7** | man years |
| **COST OF SECURITY + DONKEY HANDLERS** | **1** | **2** | **man-years** |
| | | | |
| Tot man-days for transport+security to transport Cu equiv to Ulu Burun cargo | 287 | 392 | man-days |
| Tot man-days for transport+security to transport tin per kg of copper | 0.04 | 0.04 | man-days |

| | Minimum | Maximum |
|---|---|---|
| individual donkeys | 79 | 116 |
| donkey-days | 553 | 928 |
| **donkey-years** | **2** | **3** |

**Report 6.6.6: Transportation costs for moving black copper from Timna to Piramesses (route 7)**

| TRANSPORTATION COSTS | Timna to Pi-Ramesses | | |
|---|---|---|---|
| | Min. cost | Max. cost | |
| **Manpower to control donkey teams** | | | |
| Wt of Ulu Burun copper ingots | 9,525 | 10,478 | kg |
| Carrying capacity of a donkey | 75 | 75 | kg |
| Number of donkeys required to carry the tin | 127 | 140 | |
| Minimum number of donkeys for supplies | 7 | 7 | |
| Assume no of donkeys per donkey train | 10 | 10 | |
| Number of donkey trains within the caravan | 14 | 15 | |
| No of handlers required to control one donkey team | 2 | 2 | |
| Total number of handlers | 28 | 30 | |
| Distance from Timna to Piramesses overland | 400 | 500 | km |
| Speed of donkey team | 2.8 | 2.8 | mph |
| Speed of donkey team | 4.48 | 4.48 | km/hr |
| Elapse time of journey | 89 | 112 | hrs |
| Length of shift | 8 | 8 | hrs |
| Watering/rest period | 1 | 1 | hrs |
| Length of shift less watering//rest period | 5 | 5 | hrs |
| No of days to travel to port single journey | 18 | 23 | days |
| Tot. man-days for controlling donkey teams for single jouney | 504 | 690 | man-days |
| Tot. man-years for controlling donkey teams for single jouney | **1.7** | **2.3** | **man-years** |
| **Security** | | | |
| No. of soldiers per caravan | 25 | 25 | soldiers |
| Elapse time of journey | 18 | 23 | days |
| Total security man-days | 450 | 575 | man-days |
| Total security man-years | **1.5** | **1.9** | man years |
| **COST OF SECURITY + DONKEY HANDLERS** | **3** | **4** | **man-years** |
| Tot man-days for transport+security to transport Cu equiv to Ulu Burun | 954 | 1,265 | man-days |
| Tot man-days for transport+security to transport tin per kg of copper | 0.11 | 0.13 | man-days |

**Report 6.6.7: Route taken overland by miners and smelters to Timna Route 7**

| | | | |
|---|---|---|---|
| Distance of return journey | 800 | 1,000 | km |
| Assume the men travelled at speed of a donkey | 4.48 | 4.48 | km/hr |
| Assume available hrs/days taking into account watering and rest periods | 5 | 5 | hrs |
| Elapse time of journey | 36 | 45 | days |
| | donkey trips | 134 | 147 |
| | donkey-days | 2412 | 3381 |
| | **donkey-years** | **7** | **9** |

**Report 6.6.8: Timna to Piramesses combined overland and sea (route 8)**

| | | |
|---|---|---|
| Distance overland | 155 | km |
| Distance by sea | 425 | km |
| Overland cost | 1.3 | man-years |
| Equiv't land cost travelling same distance as the sea journey | 3.4 | man-years |
| Assume Roman ratio land to sea cost | 28 | |
| Sea cost | 0.1 | |
| **Total cost of route 8** | **1.4** | **man-years** |

**Report 6.6.9: Prorating travelling time to tin/copper/bronze production**

| | Cyprus | Egypt |
|---|---|---|
| Tin | 11 | 16 |
| Copper | 2 | 4 |
| **Travelling direct manpower costs** | **13** | **20** |
| Tin | 3 | |
| Copper | 66 | 1525 |
| Charcoal tin proportional to total charcoal used by metal | 3 | 3 |
| Charcoal copper proportional to total charcoal used by metal | 24 | 28 |
| Charcoal alloying proportional to tot. charcoal used by metal | 1 | 1 |
| **Travelling indirect manpower costs** | **97** | **1557** |
| **Total travelling manpower costs** | **110** | **1577** |
| Tin | 17 | 19 |
| Copper | 92 | 1,557 |
| Alloying | 1 | 1 |
| **Total travelling manpower costs** | **110** | **1577** |

**Summary**

| Preferred routes taken in the LBA | Transport costs man-years | |
|---|---|---|
| | Cyprus | Egypt |
| Tin Uzbekistan to Ugarit (route 1) | 11 | 11 |
| Tin Ugarit to Piramesses (route 6) | - | 5 |
| Copper mines to refining centres (routes 4 and 7) | 2 | 4 |
| Supply of food to the metal workers each season | 33 | 94 |
| Transport miners food transit in/out of Timna (route 7) | - | 117 |
| Transport wood and charcoal | 28 | 31 |
| Transport drinking water for donkeys | - | 25 |
| Transport drinking water for human consumption | - | 131 |
| **Total donkey handlers man-years** | 74 | 418 |
| Time lost travelling each season | 33 | 1131 |
| Total cost of producing or buying fodder | 2 | 27 |
| **Total transport cost man-years** | **109** | **1,576** |

# Module 7: Charcoal requirement

| | | |
|---|---|---|
| Minimum weight of copper found on the Ulu burun | 9,525 | kg |
| Maximum weight of copper found on the Ulu Burun | 10,478 | kg |
| Available days for working after days lost (see mining) | 308 | days |
| Length of shift | 8 | hrs |
| Weight of the tin ingots found on the Ulu Burun | 1,000 | kg |

**Report 6.7.1: Charcoal required to smelt 1 kg of copper using results from Merkel's experimental archaeology study**

**Merkel experiment 27 and 29 based on Timna furnaces at sites 2 and 30** Merkel 1989: 222-223, Table 1 and Merkel 1983b: Table 31.

| Charcoal required to smelt 1.1 kg of copper ore | Experiment 27 | Experiment 29 | |
|---|---|---|---|
| Preheating replica of Timna funace at site 2 in kg | 16 | 20 | kg |
| Initial charge of charcoal in kg | 30 | 36 | kg |
| Total weight of charcoal in kg | 46 | 56 | kg |
| Weight of copper smelted | 1.1 | 1.1 | |
| **Total charcoal requirement to smelt one kg of copper** | **41.9** | **51** | kg |

Reference Merkel 1990: 107

| | | | |
|---|---|---|---|
| **Tot charcoal req'd to smelt equiv. wt. of copper on the Ulu Burun** | **534,378** | **kg** | |
| Top layer charcoal covering in kg | 6 | 6 | kg |
| Number of additional charges | 6 | 6 | |
| Charcoal rate/charge | 4 | 5 | kg/charge |
| Observed burning rate during smelting | 12 | 10 | kg/hr |
| Pre-heating /kg | 14.5 | 18.2 | kg |

| | | |
|---|---|---|
| **Average pre-heating** | **16.4** | kg |

Reference Timberlake 1994: 121-134.

**Report 6.7.2: Weight of charcoal required to smelt tin using the results from Timberlake's experimental archaeology study**

| Charcoal requirement to smelt the tin ore | | |
|---|---|---|
| Average charcoal requirement to smelt one kg tin ore | 70 | kg |
| Weight of tin ingots on the Ulu Burun | 1,000 | kg |
| **Total charcoal required to smelt equiv. wt. of tin on the Ulu Burun** | **70,000** | **kg** |

**Report 6.7.3: Oak required to roast Cypriot chalcopyrite and iron pyrites ore**

| | | | |
|---|---|---|---|
| Wt of oak required to roast ore to produce 1kg copper | 21.8 | kg | |
| Total wt. of oak wood to roast ore to make the Ulu Burun copper ingots | **228,420** | kg | |
| Heavy density of oaks range from | 630 | 750 | $kg/m^3$ |
| Volume of wood required | 331.0 | $m^3$ | |
| Vol. of oak required to roast ore to produce 1kg copper | **0.0316** | $m^3$ | |

Allan 1970: 10

The most comon oak is the dwarf oak (Quercus alnifolia) Knapp 1999

| | | |
|---|---|---|
| **Average** | **690** | $kg/m^3$ |

Wolffia 2007: Table 1

**Report 6.7.4: Weight of charcoal required to refine copper ingots on the Ulu Burun**

Merkel experiment 27D

| Charcoal required to refine copper ingots on the Ulu Burun | Cyprus | Egypt | |
|---|---|---|---|
| Number of refining cycles | 374 | 524 | |
| Total elapse time for one refining cycle | 11.8 | 8.27 | hrs |
| Time to complete all cycles | 4,413 | 4,333 | hrs |
| Charcoal burning rate (Merkel 1983b: Table 31; Merkel 1990: 87, Table 2) | 10 | 10 | kg/hr |
| **Total wt. of charcoal for all refinings** | **44,132** | **43,335** | kg |

Note when copper melted and refining taking place charcoal was still used over the molten Cu to provide a reductive atmosphere to prevent oxidisation of th

**Report 6.7.5: Weight of charcoal required to alloy copper and tin ingots on the Ulu Burun**

| Charcoal to alloy copper and tin ingots | Cyprus | Egypt | |
|---|---|---|---|
| No. of alloying cycles to refine equiv. wt. of copper/tin on the Ulu Burun | 410 | 574 | |
| Total elapse time for one alloying cycle It is assumed that the elapse time for alloying was of the same order as refining. | 4 | 2.46 | hrs |
| Total elapse time for alloying copper and tin equiv. wt to Ulu Burun | 1640 | 1413 | hrs |
| Charcoal burning rate | 10 | 10 | kg/hr |
| **Total wt. of charcoal for all alloying cycles** | **16,400** | **14,130** | **kg** |

**Report 6.7.6 Summary of the charcoal requirements to smelt, refing and alloy the weight of copper and tin on the Ulu Burun**

| Process | Cyprus | Egypt |
|---|---|---|
| Smelting copper | 534,378 | 534,378 |
| Refining copper | 44,132 | 43,335 |
| Smelting tin | 70,000 | 70,000 |
| Alloying copper and tin | 16,400 | 14,130 |
| **Total charcoal requirement kg** | **664,910** | **661,843** |

**Report 6.7.6a**

| Process | Cyprus | Egypt |
|---|---|---|
| Smelting copper | 534,378 | 534,378 |
| Refining copper | 44,132 | 43,335 |
| Total smelting and refining copper | **578,510** | **577,713** |
| Smelting tin | 70,000 | 70,000 |
| Alloying copper and tin | 16,400 | 14,130 |
| **Total charcoal requirement kg** | **664,910** | **661,843** |

**Report 6.7.6b**

| Percentage use of charcoal for each process | | |
|---|---|---|
| Total smelting and refining copper | **87.0** | **87.3** |
| Smelting tin | **10.5** | **10.6** |
| Alloying copper and tin | **2.5** | **2.1** |
| **Percentage charcoal requirement** | **100.0** | **100.0** |

**Report 6.7.7 Charcoal requirements to smelt, refing and alloy one kg of bronze**

| | | |
|---|---|---|
| Weight of the copper ingots on the Ulu Burun | 10,478 | kg |
| Weight of the tin ingots on the Ulu Burun | 1,000 | kg |
| Combined weight of the copper and tin ingots on the Ulu Burun | 11,478 | kg |

**Report 6.7.7a: Summary**

| Charcoal requirements to smelt, refing and alloy one kg of bronze | |
|---|---|
| Cyprus | Egypt |
| **58** | **57.7** |

**Report 6.7.7b: Deforestation**

| | | | |
|---|---|---|---|
| Area of Polis (Cyprus) forest cover | 129.1 | km2 | Raber 1984: 304 |
| Density of trees | 125 | trees/acre | Allan 1970: 10 |
| | 309 | trees/ha | |
| Min. weight of wood that could be felled from one sq km (100 ha)/yr | 197,643 | kg/yr/km2 | Raber 1984: Table 2. |
| Max. weight of wood that could be felled from one sq km (100 ha)/yr | 1,322,767 | kg/yr/km2 | |

**Report 6.7.8a: Total volume of wood required to produce the charcoal to smelt, refine and alloy the copper and tin ingots on the Ulu Burun**

| Total vol. of wood required to produce the charcoal to smelt, refine and alloy the copper and tin ingots on the Ulu Burun | Cyprus | Timna |
|---|---|---|
| Total requirement for charcoal kg | 664,910 | 661,843 |
| Ratio wood to charcoal in kg | 5.7 | 7 |
| Weight of wood required to roast Cypriot ore | 228,420 | |
| Total weight of wood required kg | 4,018,407 | 4,632,900 |
| Assume average density of wood in kg/m³ | 630 | 750 |
| **Total volume of wood required in m3** | **6378** | **6177** |
| Total weight of wood required for charcoal alone kg | 3,789,987 | 4,632,900 |

**Report 6.7.8b: Wood to charcoal ratios**

| Ratio wood to charcoal | Total bronze manpower Cyprus | Total bronze manpower Timna | | Cyprus | Timna |
|---|---|---|---|---|---|
| 1: 5.7 and 1:5.7 | 5,533 | 9,221 | Maximum | 5,798 | 9,548 |
| 1:7 and 1:5.7 | 5,798 | 9,430 | Minimum | 5,533 | 9,221 |
| 1:5.7 and 1:7 | 5,533 | 9,338 | Range | 265 | 327 |
| 1:7 and 1:7 | 5,798 | 9,548 | % | 4.6 | 3.4 |

**Report 6.7.8c: Summary**

| Wood requirements for the Ulu Burun study | Cyprus | Timna |
|---|---|---|
| Weight of wood required for roasting ore, firesetting, and charcoal needed for the Ulu Burun case study | 4,018,407 | 4,632,900 |
| Vol. of wood required m³ | 6378 | 6177 |
| Number of trees required assuming only one third of the tree suitable for charcoal | 105,748 | 154,430 |

**Report 6.7.9: Man-years of lumbering effort to cut sufficient wood to meet charcoal requirements for smelting, refining and alloying the copper and tin ingots on the Ulu Burun**

| Man-years of lumbering effort to cut sufficient wood to meet charcoal requirements | Cyprus | Timna |
|---|---|---|
| Total weight of wood required kg | 4,018,407 | 4,632,900 |
| Wt of suitable wood for charcoal from an average sized tree | 38 | 30 |
| Tot no. of trees felled based on Baskerville/Rothenburg's assumptions | 105,748 | 154,430 |
| Number of trees required to make 1,000 kg bronze | 9,212 | 13,453 |
| Number of hours to cut, trim, and stack wood | 6.5 | 6.5 |
| Total hrs require to cut wood | 687,359 | 1,003,795 |
| No. of man-days to cut wood | 85,920 | 125,475 |
| **No. of man-years to cut wood** | **279** | **408** |
| No. of man-days to cut wood per kg of bronze produced | 7.49 | 10.93 |
| * Felling trees (1 man cutting + 2 men with ropes), rate 1.5 man-hours/man | 4.5 | hrs |
| Time to cut, trim and stack one tree | 2 | hrs |
| Total time per tree | 6.5 | hrs |

| | | |
|---|---|---|
| Baskerville 1965: 867 (Cyprus) and Rothenbe | | Rothenburg 1978: 9. |
| Pine trees 10 inches diam branches weigh kg | 38 | |

| | | | |
|---|---|---|---|
| Vol./ha of deciduous oak forest | 1200 | m³/ha | Waters and Chrisie 1958: 1-31 |
| % branches | 50 | % | Waters and Chrisie 1958: 1-31 |
| % branches | 33 | % | Cleere 1976: 240 |
| Net wood for charcoal prod'n. | 400 | m³/ha | Cleere 1976: 240 |

* Shirley 2001: 41. Also see Cleere and Crossley 1985: 133-135.

**Report 6.7.10a: Manpower requirements to make and operate the charcoal clamp and pit kilns**

| | Cyprus | Timna | |
|---|---|---|---|
| **Days to build and pull down clamp plus break up/sort charcoal for transp'rt | 4.5 | 4.5 | days |
| Men per 12 hr shift for the burn cycle | 2 | 2 | |
| Elapse production time | 68 | 68 | hrs |
| Man-days per cycle | 20.3 | 20.3 | man-days |
| Weight of charcoal produced per cycle | 100 | 100 | kg |
| Tot wt of charcoal to smelt, roast, refine and alloy the UB ingots | 664,910 | 661,843 | kg |
| No. of cycles, uplifted to take into account air ingress causing combustion | 7,646 | 7,611 | |
| Total number of man-days | 155,223 | 154,507 | man-days |
| **Total number of man-years** | **504** | **502** | man-years |

** Personal communication with Paul Pinnington, traditional charcoal maker at the Weald and Downland Museum, Singleton, Hants, UK. http://www.wealddown.co.uk

**Report 6.7.10b**

| | Unit charcoal production rates Cyprus | Timna | |
|---|---|---|---|
| Pleiner 2000: 126 | | | |
| Pleiner 2000: 126 | | | |
| Report 4.8.8 | 0.680 | 0.680 | hrs/kg charcoal |
| % uplift to account for complete or partial combustion of wood due to ingress of air | 15 | | |
| **Man-days per kg charcoal produced** | **0.233** | **0.233** | man-days/kg |

**Report 6.7.11: Transport requirements to transport charcoal and wood to the charcoal production sites**

| Transport requirements to transport charcoal | Cyprus | | Timna | | Units |
|---|---|---|---|---|---|
| | Min. cost | Max. cost | Min. cost | Max. cost | |
| Distance to transport wood to charcoal maker | 4 | 8 | 8.5 | 17 | km |
| Speed of donkey train | 2.8 | 2.8 | 2.8 | 2.8 | miles/hr |
| Speed of donkey train | 4.48 | 4.48 | 4.48 | 4.48 | km/hr |
| Time of journey out and back | 1.8 | 3.6 | 3.8 | 7.6 | hrs |
| Carrying capacity of a donkey based on weight in kg | 75 | 75 | 75 | 75 | hrs |
| Tot. wt. of charcoal required in kg | 664,910 | 664,910 | 661,843 | 661,843 | kg |
| Uplifted charcoal requirement | 764,647 | 764,647 | 761,119 | 761,119 | kg |
| No individual donkey return trips to charcoal maker | 10,195 | 10,195 | 10,148 | 10,148 | |
| No of donkeys in train | 10 | 10 | 10 | 10 | |
| No of donkey trains out and return | 1,020 | 1020 | 1,015 | 1015 | hrs |
| Total travelling out and back in hrs | 1,836 | 3672 | 3,857 | 7714 | hrs |
| Time to load/unload animals in hrs | 1.5 | 1.5 | 1.5 | 1.5 | hrs |
| Total elapse time to load/unload all donkeys | 1,530 | 15,293 | 1,523 | 15,222 | hrs |
| Total elapse time in hrs for return trip and loading/unloading donkeys | 3,366 | 18,965 | 5,380 | 22,936 | hrs |
| Time taken for watering/rest periods in hrs | 1 | 1 | 1 | 1 | hrs |
| Length of shift less watering//rest period in hrs | 5 | 5 | 5 | 5 | days |
| Total length of return journey | 306 | 3059 | 305 | 3045 | days |
| No of days elapsed per donkey train | 673 | 3,793 | 1,076 | 4,587 | |
| No. of men required to look after each donkey train | 2 | 2 | 2 | 2 | man-days |
| Total transportation man-days | 1,346 | 7,586 | 2,152 | 9,175 | man-days |
| **Total number of man-years** | **5** | **25** | **7** | **30** | man-years |

Ratio of elapse times for 5 and 10 km journeys 5.6

| | |
|---|---|
| Distance km Yotvatah to Timna | 17 |
| Distance km Wadi Arabah to Timna | 8.5 |
| Horne 1982b: 205 | |
| Aluja 2001: 271-278 | |
| Percentage lost in transport | 15 |

Assumes watering start of day, mid-day and evening

| Cyprus | Minimum | Maximum |
|---|---|---|
| indiv donk' trips | 10,195 | 10,195 |
| donkey-days | 3,670 | 7,341 |
| donkey-years | 10 | 20 |
| Timna | Minimum | Maximum |
| donkey trips | 10,148 | 10,148 |
| donkey-days | 7,713 | 15,425 |
| donkey-years | 21 | 42 |

**Report 6.7.12: Total manpower resources required to supply charcoal to the metal workers producing the Ulu Burun copper and tin ingots**

Pleiner 2000: 126 experimental results based on texts and wood engravings in Pirotechnia written by Vanoccio Biringuccio (1540 A.D.)

| | | | |
|---|---|---|---|
| Charcoal production man-days per kg of charcoal | 0.203 | 0.202 | man-days/kg |

| | Cyprus | Timna | |
|---|---|---|---|
| Total weight of charcoal required | 764,647 | 764,647 | kg |
| No. man-days to produce total charcoal requirement | 155,223 | 154,507 | man-days |
| No. man-days to cut trees to make the total charcoal requirement | 85,920 | 125,475 | man-days |
| No. of man-days to transport charcoal | 7,586 | 9,175 | man-days |
| **Total man-days of effort** | **248,729** | **289,157** | man-days |
| **Total man-years of effort** | **808** | **939** | **man-years** |
| Total man-days per kg of charcoal | 0.325 | 0.378 | man-days/kg |

**Report 6.7.13: Prorated charcoal manpower proportional to the percentage charcoal requirement by process**

| From Report % charcoal requirement | Cyprus | Timna |
|---|---|---|
| Total smelting and refining copper | 87.0 | 87.3 |
| Smelting tin | 10.5 | 10.6 |
| Alloying copper and tin | 2.5 | 2.1 |
| **Percentage charcoal requirement** | **100.0** | **100.0** |
| **Prorated man-power** | **Cyprus** | **Timna** |
| Total smelting and refining copper | 703 | 819 |
| Smelting tin | 85 | 100 |
| Alloying copper and tin | 20 | 20 |
| **Prorated manpower** | **808** | **939** |
| Total man-years less trasport | 783 | 910 |

# Module 8: Manpower required to supply food, fodder, and supplies to the metal workers

**Report 6.8.2: Man-years lost in unproductive travel from Piramesses to Timna and return**

| | Cyprus | Timna |
|---|---|---|
| Days travel to and return from mininig sites per season | 2 | 45 |
| Tot man-days incurred in the return journey from Piram's to Timna | 10,126 | 348,390 |
| Tot man-years incurred in the return journey from Piram's to Timna | 33 | 1131 |

**Report 6.8.3: Man-years transporting grain and pulses to feed metal workers**

| Grain and Pulses transported<br>Journey | Cypriot agricultural hinterland | Timna agricultural hinterland | Piram-Timna supplies for return journey | |
|---|---|---|---|---|
| **From Report 2.4e in AGCALC. Assume only grain and pulses transported by donkey. Protein obtained locally.** | | | | |
| Grain for bread | 225 | 225 | 225 | kg/yr/worker |
| Grain for production of beer | | 0 | | kg/yr/worker |
| Pulses | 75 | 75 | 75 | kg/yr/worker |
| **Total weight of grain and pulses transported** | **300** | **300** | **300** | **kg/yr/worker** |
| No. of man-years working at site or lost travelling to site | 5,063 | 7,742 | 1,131 | |
| Total grain and pulses requirement | 1,518,900 | 2,322,600 | 339,300 | kg |
| Assume average return distance from food source to mines | 50 | 100 | 880 | km |
| Load per donkey | 75 | 75 | 75 | kg |
| No of donkeys in train | 10 | 10 | 10 | |
| No of individual donkey trips | 20,252 | 30,968 | 4,524 | |
| Speed of donkey | 4.48 | 4.48 | 4.48 | km/hr |
| Time for journey | 11.16 | 22.32 | 196.43 | hrs |
| Time to unload per journey | 1 | 1 | 1 | hrs |
| Total time forreturn journey plus unloading | 12.16 | 23.32 | 197.43 | hrs |
| Length of shift | 8 | 8 | 8 | hrs |
| Watering/rest period | 1 | 1 | 1 | hrs |
| Number of rest stops per day | 3 | 3 | 3 | |
| Length of shift less watering//rest period | 5 | 5 | 5 | hrs |
| Total time for journey and unloading | 2.44 | 4.67 | 39.49 | days |
| No of men per donkey train | 2 | 2 | 2 | |
| Total handler man-days | 9,883 | 28,924 | 35,731 | man-days |
| **Total handler man-years** | **33** | **94** | **117** | **man-years** |
| **Total handler man-years for transport local sourced food + food required for while workers in transit from Piramesses to Timna and return** | | **211** | **man-years** | |

* For humans see http://www.csgnetwork.com/humanh2owater.html

**Report 6.8.1a: Summary of manpower linked to the production of copper and tin found on the Ulu Burun wreck (alloying to make bronze excluded)**

| Process | Cyprus | Timna |
|---|---|---|
| Miners | 434 | 3,003 |
| Firesetting | 33 | 33 |
| Beneficiation | 3,537 | 3,537 |
| Roasting | 21 | |
| Smelters | 250 | 250 |
| Charcoal workers | 788 | 919 |
| **Total** | **5,063** | **7,742** |

**Report 6.8.1b: Summary of manpower linked to the end to end bronze production process assuming the copper and tin on the Ulu Burun was made into bronze**

| Process | Cyprus | Timna |
|---|---|---|
| Miners | 434 | 3,003 |
| Firesetting | 33 | 33 |
| Beneficiation | 3,537 | 3,537 |
| Roasting | 21 | 0 |
| Smelters | 250 | 250 |
| Refining | 10 | 12 |
| Alloying | 4 | 4 |
| Charcoal workers | 808 | 939 |
| Transport | 110 | 1577 |
| **Total** | **5,207** | **9,355** |

| | Cyprus | Timna |
|---|---|---|
| donkey trips | 20,252 | 30,968 |
| donkey-days | 49,415 | 144,621 |
| **donkey-years** | **135** | **396** |

**Supplies for each season return journey Piram-Timna**

| | Timna |
|---|---|
| donkey trips | 4,524 |
| donkey-days | 178,653 |
| **donkey-years** | **489** |

**Report 6.8.4: Man-years transporting water from Ein Radiyan to Timna**

| | Humans | Donkeys | |
|---|---|---|---|
| Daily water requirement * | 3.5 | 27 | litres/day |
| Dailey weight of water * | 3.5 | 27 | kg |
| Assume length of mining season | 180 | 180 | days |
| No. of man-years working at site or donkey years at site | 7,742 | 221 | years |
| Total water requirement | 4,877,460 | 1,071,630 | kg |
| Distance Ein Radiyan to and from Timna | 30 | 30 | km |
| Load per donkey | 75 | 75 | kg |
| No of donkeys in train | 10 | 10 | |
| No of individual donkey trips out and return | 65,033 | 14,288 | |
| Speed of donkey | 4.48 | 4.48 | km/hr |
| Time for journeys | 6.7 | 6.7 | hrs |
| Time to unload per journey | 1 | 1 | hrs |
| Total time for journey and unloading | 7.7 | 7.7 | hrs |
| Length of shift | 8 | 8 | hrs |
| Watering/rest period | 1 | 1 | hrs |
| Number of rest stops per day | 3 | 3 | |
| Length of shift less watering//rest period | 5 | 5 | hrs |
| Total time for return journey and unloading | 3.08 | 3.08 | days |
| No of men per donkey train | 2 | 2 | |
| Total handler man-days | 40,061 | 8,802 | man-days |
| **Total handler man-years** | **131** | **25** | **man-years** |
| **Tot. handlers to bring in water for workers + donkeys** | **156** | **man-years** | |

* For donkeys see Aganga and Letso 2000.

Assume half of demand for water for donkeys satisfied at start of journey at Ein Radiyan

Assume water transport for donkeys required only for cahrcoal and food supply at Timna

| **Water for donkeys** | |
|---|---|
| | Timna |
| donkey trips | 14,288 |
| donkey-days | 44,007 |
| donkey-years | **121** |
| **Water for humans** | |
| | Timna |
| donkey trips | 65,033 |
| donkey-days | 200,302 |
| donkey-years | **549** |

**Report 6.8.5: Summary of the man-years for security and donkey handlers**

| Route taken | Donkey handlers | |
|---|---|---|
| | Cyprus | Egypt |
| Tin Uzbekistan to Ugarit (route 1) | 11 | 11 |
| Tin Ugarit to Piramesses (route 6) | - | 5 |
| Copper mines to refining centres (routes 4 and 7) | 2 | 4 |
| Supply of food to the metal workers each season | 33 | 94 |
| Transport miners food transit in/out of Timna (route 7) | - | 117 |
| Transport wood and charcoal | 28 | 31 |
| Transport drinking water for donkeys | - | 25 |
| Transport drinking water for human consumption | - | 131 |
| **Total donkey handlers man-years** | **74** | **418** |

**Report 6.8.7: Man-years for donkey handlers + security for wood and charcoal**

| | Donkey-years of effort | |
|---|---|---|
| | Cyprus | Egypt |
| Moving wood for firesetting | 1 | 1 |
| Moving wood for refining | 2 | - |
| Moving charcoal | 25 | 30 |
| **Total donkey-years** | **28** | **31** |

**Report 6.8.6: Summary of the donkey-years required for food and water supplies**

| Route taken | Donkey-years of effort | |
|---|---|---|
| | Cyprus | Egypt |
| Tin Uzbekistan to Ugarit (route 1) | 5 | 5 |
| Tin Ugarit to Piramesses (route 6) | - | 5 |
| Copper mines to refining centres (routes 4 and 7) | 3 | 9 |
| Supply of food to the metal workers each season | 135 | 396 |
| Transport food to supply miners while transit in/out of Timna (route 7) | - | 489 |
| Transport wood and charcoal | 31 | 45 |
| Transport drinking water for donkeys | - | 121 |
| Transport drinking water for human consumption | - | 549 |
| **Total donkey-years** | **174** | **1619** |

| | | |
|---|---|---|
| Total donkey-years required for the Ulu Burun case study | 174 | 1619 |
| Man-days to grow and harvest alfalfa for one donkey/year | 2 | 5 |
| Total man-days to grow and harvest alfalfa for one donkey/year | 348 | 8095 |
| **Total man-years to grow and harvest fodder for one donkey/year** | **2** | **27** |

* see page 249 Final diet 6a

**Report 6.8.8: Donkey-years for food and water supplies**

| | Donkey-years of effort | |
|---|---|---|
| | Cyprus | Egypt |
| Wood for firesetting extract'n of tin | 3 | 3 |
| Wood for refining | 8 | - |
| Moving charcoal | 20 | 42 |
| **Total donkey-years** | **31** | **45** |

# Module 9: Bronze required to supply the Egyptian Army at the Battle of Kadesh

**Report 6.9.1: Bronze requirement to supply Egyptian standing army in the time of Ramesses II**

**Example - Army of Rameses II**
Numbers deduced from the analysis of the army of Ramesses II by Spalinger 2005: 202 205, 214-230,

| | Number of soldiers at Kadesh | Border soldiers in Nubia, Libya etc | Total |
|---|---|---|---|
| Chariot drivers | 2,500 | 500 | 3,000 |
| Chariot Archers | 2,500 | 500 | 3,000 |
| Archers | 5,000 | 1,500 | 6,500 |
| Infantry | 20,000 | 7,500 | 27,500 |
| Total | **30,000** | **10,000** | **40,000** |

| Bronze Required kg High Case | No. of weapons to support army of 40,000 soldiers | Unit weight of bronze kg | No of weapons | Wt. of bronze required kg | |
|---|---|---|---|---|---|
| Bronze cheekpieces, rings and bits on chariot horses | 3,000 | 1 | 1 | 3,000 | Azzaroli 1985. Estimate from drawings in Littauer 1979 |
| Chariot arrow heads | 3,000 | 0.00605 | 80 | 1,452 | Yalçin et al 2005: 623 and Wernick 2004: 151-155. |
| Charioteers mail coeselet | 3,000 | 6.1 | 1 | 18,300 | Estimate from drawing in Partridge 2002: 55 |
| Archers arrow heads | 7,500 | 0.00605 | 80 | 3,630 | Yalçin et al 2005: 623 |
| Archers, officers and elite infantry headgear | 9,500 | 0.5 | 1 | 4,750 | Estimate using McDermott 2004: 138-139 & Partridge 2002: 57. |
| Spear heads | 27,500 | 0.132 | 1 | 3,630 | Yalçin et al 2005: 622 |
| Nails in infantry shields | 30,500 | 0.007 | 1 | 214 | McDermott 2004: 145-146 |
| Battle Axes | 10,000 | 1 | 1 | 10,000 | Beit-Arieh 1985: 96 |
| Chariot officer's Khopesh Swords | 2,500 | 2 | 1 | 5,000 | Estimate from drawing in Wernick 2004: 155. |
| Officers Daggers | 400 | 0.2 | 1 | 80 | Yalçin et al 2005: 620-621 |
| | | | | **50,056** | Assumed recycling rate 50 % |
| **Ratio estimate of bronze required compared with the weight of copper and tin on the Ulu Burun wreck** | | | | **4.4** | **2.2** |

| Bronze Required kg High Case | No. of weapons to support army of 40,000 soldiers | Unit weight of bronze kg | No of weapons | Wt. of bronze required kg |
|---|---|---|---|---|
| Bronze cheekpieces, rings and bits on chariot horses | 2,500 | 1 | 1 | 2,500 |
| Chariot arrow heads | 2,500 | 0.00605 | 80 | 1,210 |
| Charioteers mail corselet | 2,500 | 6.1 | 1 | 15,250 |
| Archers arrow heads | 7,500 | 0.00605 | 80 | 3,630 |
| Archers, officers and elite infantry headgear | 7,500 | 0.5 | 1 | 3,750 |
| Spear heads | 20,000 | 0.132 | 1 | 2,640 |
| Nails in infantry shields | 20,000 | 0.007 | 1 | 140 |
| Battle Axes | 6750 | 1 | 1 | 6,750 |
| Officer's Khopesh Swords | 300 | 2 | 1 | 600 |
| Officers Daggers | 300 | 0.2 | 1 | 60 |

Assumed recycling rate 50 %

**1.6**

| Total Weight of bronze required kg | Ratio estimate of bronze required compared with the weight of copper and tin on the Ulu Burun wreck |
|---|---|
| **36,530** | **3.2** |

**Report 6.9.2: Estimate of the weight of a bronze corslet from drawing of a relief in the Mortuary Temple of Ramesses II**

Drawing ref Partridge 2002: 55

Replica of Tyryns waste length made from bronze plates weighed 4.5 kg see http://www.larp.com/hoplite/BAarmor.html#armor

| Chariots | Large | Medium | Small | |
|---|---|---|---|---|
| Corslet | 270 | 44 | 34 | plates |
| Thickness | 0.001 | 0.001 | 0.001 | m |
| Length | 0.071 | 0.008 | 0.003 | m |
| Width | 0.03925263 | 0.0024 | 0.002 | m |
| Volume of Bronze | 0.00075 | 0.000000845 | 0.0000002 | $m^3$ |
| Density of Bronze | 8100 | 8100 | 8100 | $kg/m^3$ |
| Weight | 6.075 | 0.0068445 | 0.00162 | kg |
| | | Total weight | **6.1** | kg |

**Report 6.9.3: Estimate of the weight of a bronze tips on ploughing ards and hoes**

Linked to cell I598 in BRONZE cell I958

Linked to cell N1 in Brick manpower

| | | |
|---|---|---|
| Percentage farms with a plough | 25 | 50 |
| No. of farms per 100,000 population | 17,889 | 17,889 |
| Population of Egypt in the LBA | 2,200,000 | 2,200,000 |
| Number of ploughs | 98,390 | 196,779 |
| Wt of bronze plough tip kg | 1.02 | 1.02 |
| Total weight of bronze plough tips kg | 100,358 | 200,715 |
| Number of bronze hoe tips/farm | 1 | 1 |
| Percentage of farms with a hoe | 25 | 50 |
| No. of plough tips | 9,839 | 19,678 |
| Weight of bronze hoe head kg | 0.46 | 0.46 |
| Total weight of bronze hoe tips kg | 99,570 | 199,140 |
| Combined wt. of plough + hoe tips kg | 199,928 | 399,855 |
| No. of equivalent Ulu Burun cargoes | 17.5 | 34.9 |

**Dimensions taken from Bass 1967: 89, figure 102.**

| | | | | | |
|---|---|---|---|---|---|
| Length of plough tip B48 | 0.21 | m | Length of hoe tip B47 | 0.14 | m |
| Width main blade | 0.05 | m | Width main blade | 0.04 | m |
| Mean length socket sections | 0.05 | m | Mean length socket sections | 0.035 | m |
| Mean width | 0.02 | m | Mean width | 0.02 | m |
| Mean thickness | 0.01 | m | Mean thickness | 0.008 | m |
| Volume | 0.000125 | $m^3$ | Volume | 0.000056 | $m^3$ |
| Density of bronze | 8100 | $kg/m^3$ | Density of bronze | 8100 | $kg/m^3$ |
| Weight of plough tip | 1.02 | kg | Weight of plough tip | 0.46 | kg |

**Report 6.9.4: Bronze requirement to support craftsmen in LBA Egypt**

| | Percentage adult males with tools | 1 | 2 | 5 | 7 | 10 |
|---|---|---|---|---|---|---|
| | Number of males in LBA Egypt | 1,100,000 | 1,100,000 | 1,100,000 | 1,100,000 | 1,100,000 |
| Report 2.7A in AGCALC | % males aged 16-50 | 45.6 | 45.6 | 45.6 | 45.6 | 45.6 |
| | Number of males aged 16-50 | 501,600 | 501,600 | 501,600 | 501,600 | 501,600 |
| | Number of craftsmen | 5,016 | 10,032 | 25,080 | 35,112 | 50,160 |
| | Assume average weight of tools kg | 1 | 1 | 1 | 1 | 1 |
| | Total weight of tools kg | 5,016 | 10,032 | 25,080 | 35,112 | 50,160 |
| | No. of equivalent Ulu Burun cargoes | 0.5 | 0.9 | 2.2 | 3.1 | 4.4 |
| | Assume average weight of tools kg | 2 | 2 | 2 | 2 | 2 |
| | Total weight of tools kg | 10,032 | 20,064 | 50,160 | 70,224 | 100,320 |
| | No. of equivalent Ulu Burun cargoes | 0.9 | 1.8 | 4.4 | 6.2 | 8.8 |
| | Assume average weight of tools kg | 3 | 3 | 3 | 3 | 3 |
| | Total weight of tools kg | 15,048 | 30,096 | 75,240 | 105,336 | 150,480 |
| | No. of equivalent Ulu Burun cargoes | 1.4 | 2.7 | 6.6 | 9.2 | 13.2 |
| | Assume average weight of tools kg | 4 | 4 | 4 | 4 | 4 |
| | Total weight of tools kg | 20,064 | 40,128 | 100,320 | 140,448 | 200,640 |
| | No. of equivalent Ulu Burun cargoes | 1.8 | 3.5 | 8.8 | 12.3 | 17.5 |

| Average weight (kg) of tools used per craftsman | Percentage of Egyptian adult males who were craftsmen | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 5 | 7 | 10 |
| | Equivalent number of Ulu Burun copper and tin cargo | | | | |
| 1 | 0.5 | 0.9 | 2.2 | 3.1 | 4.4 |
| 2 | 0.9 | 1.8 | 4.4 | 6.2 | 8.8 |
| 3 | 1.4 | 2.7 | 6.6 | 9.2 | 13.2 |
| 4 | 1.8 | 3.5 | 8.8 | 12.3 | 17.5 |

**Report 6.9.5: Bronze requirement to support army of Ramesses II assuming that corselets and helmets weighed the same as those from Nuzi**

**Example - Army of Rameses II**

Nos. deduced from the analysis of the army of Ramesses II, Spalinger 2005: 202-205, 214-230.

| | Number of soldiers at Kadesh | Border soldiers in Nubia, Libya etc | Total |
|---|---|---|---|
| Chariot drivers | 2,500 | 500 | 3,000 |
| Chariot Archers | 2,500 | 500 | 3,000 |
| Archers | 5,000 | 1,500 | 6,500 |
| Infantry | 20,000 | 7,500 | 27,500 |
| Total | **30,000** | **10,000** | **40,000** |

| Bronze Required kg High Case | Number of soldiers | Unit weight of bronze kg | No of weapons | Wt. of bronze required kg | |
|---|---|---|---|---|---|
| Bronze cheekpieces, rings and bits on chariot horses | 3,000 | 1 | 1 | 3,000 | Azzaroli 1985. Estimate from drawings in Littauer 1979 |
| Chariot arrow heads | 3,000 | 0.00605 | 80 | 1,452 | Yalçin et al 2005: 623 and Wernick 2004: 151-155. |
| Charioteers mail corselet 1 | 3,000 | 4.7075 | 1 | 14,123 | Estimate from drawing in Partridge 2002: 55 |
| Archers arrow heads | 7,500 | 0.00605 | 80 | 3,630 | Yalçin et al 2005: 623 |
| Archers, officers and elite infantry headgear 2 | 9,500 | 1.99 | 1 | 11,817 | Dezső 2002 |
| Spear heads | 27,500 | 0.132 | 1 | 3,630 | Yalçin et al 2005: 622 |
| Nails in infantry shields | 30,500 | 0.007 | 1 | 214 | McDermott 2004: 145-146 |
| Battle Axes | 10,000 | 1 | 1 | 10,000 | Beit-Arieh 1985: 96 |
| Officer's Khopesh Swords | 2,500 | 2 | 1 | 5,000 | Estimate from drawing in Wernick 2004: 155. |
| Officers Daggers | 400 | 0.2 | 1 | 80 | Yalçin et al 2005: 620-621 |
| | | | | **52,946** | Assume 50% rcycling |
| **Ratio estimate of bronze required compared with the weight of copper and tin on the Ulu Burun** | | | | **4.7** | **2.35** |

| Bronze Required kg Low case | Number of soldiers | Unit weight of bronze kg | No of weapons | Wt. of bronze required kg |
|---|---|---|---|---|
| Bronze cheekpieces, rings and bits on chariot horses | 2,500 | 1 | 1 | 2,500 |
| Chariot arrow heads | 2,500 | 0.00605 | 80 | 1,210 |
| Charioteers mail corselet 1 | 2,500 | 1.176875 | 1 | 2,943 |
| Archers arrow heads | 7,500 | 0.00605 | 80 | 3,630 |
| Archers, officers and elite infantry headgear 2 | 7,500 | 1.99 | 1 | 9,329 |
| Spear heads | 20,000 | 0.132 | 1 | 2,640 |
| Nails in infantry shields | 20,000 | 0.007 | 1 | 140 |
| Battle Axes | 6750 | 1 | 1 | 6,750 |
| Officer's Khopesh Swords | 300 | 2 | 1 | 600 |
| Officers Daggers | 300 | 0.2 | 1 | 60 |
| | | | | **29,802** |
| **Ratio estimate of bronze required compared with the weight of copper and tin on the Ulu Burun** | | | | **2.6** |

Assume 50% rcycling

**1.3**

| | Nuzi charioteers' scale armour kg | Nuzi charioteers' scale helmet kg* |
|---|---|---|
| Refs.of texts and analysis see Dezső 2002: 195-216, particularly Diagrams 1-2. | 22.5 | 2.14 |
| | 22.5 | 2.14 |
| | 18.88 | 1.5 |
| | 15.06 | 1.82 |
| | 16.56 | 2.03 |
| | 21.6 | 2.03 |
| | 20.25 | 2.03 |
| | 17.89 | 2.03 |
| | 14.26 | 2.03 |
| | | 2.14 |
| Average | 18.83 | 1.99 |

[1]Only 25% estimated to have scale armour helmets the rest had leather designs with bronzr reinforcement kg = 0

[2]Only 25% estimated to have scale armour helmets the rest had leather designs with bronzr reinforcement kg = 0.5

**Report 6.10: Estimation of the population of LBA Cyprus**

**Site areas ha**

| | | |
|---|---|---|
| No of sites proBA Knapp 1993: 93 fig 3 | 308 | |
| Uplift for unkown sites | 1 | |
| Assume average site size ha Knapp 1992: 93 fig 3 | 35 | |
| Area | **10,780** | |
| Population density/ha Manning 1993: 42 | 35 | minmum |
| | 160 | maximum |
| Estmated population | **377,300** | maximum |
| | **1,724,800** | minimum |

**CIA factsheet https://www.cia.gov/library/publications/the-world-factbook/geos/cy.html#Geo**

| | | |
|---|---|---|
| Arable land | 10.81 | % |
| Permanent crops | 4.3 | % |
| | 15.11 | |

| | | |
|---|---|---|
| **Total area o Cyprus** | **9,250** | **km2** |
| Case 1: Based on tot. area of permanent crops in Cyprus 2006, 4.3 % | 398 | km2 |
| | 39,780 | ha |
| Case 2: Based on tot. area of arable land in Cyprus 2006, 4.3 % | 1,398 | km2 |
| | 139,770 | ha |

| | | |
|---|---|---|
| Area of grain less that for seed corn to feed/100,000 poulation | 56,825 | ha |
| Total energy to feed 100,000 people less seed corn and dairy,protein etc | 64,938 | million kcals/yr |

**Case 1: Minimum population based on same ratio as permanent crops**

| | |
|---|---|
| Total population supported | **142,848** |
| Assume rounded number | **150,000** |

**Case 2: Maximum population based on same ratio as total arable land**

| | |
|---|---|
| Total population supported | **351,357** |
| Thesis assumption | **200,000** |

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